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**Performance of water temperature management on the  
Klamath and Trinity rivers, 2016**

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*Abstract.*— Water temperature is a fundamental driver of aquatic ecosystems, necessitating water temperature management to conserve imperiled aquatic species. In the western United States, increased summer water temperatures resulting from human modification of river ecosystems have been implicated in the decline of Pacific salmon populations. The potential for deleterious effects of high water temperatures on the survival of salmonids and other native aquatic species led to water temperature specific management actions in northern California's Klamath River basin, and water temperature monitoring by the U.S. Fish and Wildlife Service. Here we summarize the results of 2016 water temperature monitoring for a set of focal locations established within the anadromous portion of the Klamath basin and place these results within the context of previous temperature data. We also evaluate the effect of late-summer to early-fall releases of cold water from Trinity Reservoir that were intended to reduce Klamath River water temperatures in the seven years this management action has been applied. Klamath River and lower Trinity River water temperatures frequently (2016 range: 23 to 156 days) exceeded EPA criteria for Pacific Northwest water temperatures (applied to the Klamath locations), and a basin-specific water temperature objective (applied to the lower Trinity River), both in 2016 and previous years. Water temperatures further upstream in the Trinity River less frequently (2016 range: 3 to 14 days) exceeded specified objectives. Late-summer to early-fall supplemental releases from Trinity Reservoir had a moderate cooling effect on lower Klamath water temperatures and were largely successful at achieving the temperature objective associated with the releases. We suggest further watershed restoration and improved water management in the basin are necessary to restore cooler and more natural thermal regimes to the Klamath River and its tributaries.

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## Introduction

Water temperature is a fundamental ecosystem parameter that affects all aquatic organisms (Beitinger and Fitzpatrick 1979; Ward and Stanford 1982; Beschta et al. 1987). For example, water temperature influences ecosystem metabolism (Yvon-Durocher et al. 2012), growth rates (Brett 1971), species distributions (Shuter and Post 1990), interspecific-competition (Reeves et al. 1987), and disease dynamics (Ray et al. 2014). Human modification of river ecosystems has often resulted in elevated water temperatures (Poole and Berman 2001; USEPA 2003; Caissie 2006), negatively impacting Pacific salmon (*Oncorhynchus* spp) populations and other cold water-adapted species along the west coast of North America (NAS 1996; McCullough 1999; Bury 2008; Gerick et al. 2014), including the Klamath River basin of northern California and southern Oregon.

The Klamath River basin historically supported large runs of Chinook Salmon (*O. tshawytscha*), Coho Salmon (*O. kisutch*), steelhead (*O. mykiss*), and other anadromous fishes (KRBFTF 1991; NAS 2004; USDOJ and NMFS 2012). These species contribute to economically and culturally important subsistence, sport, and commercial fisheries. However, abundances of anadromous fish species have declined dramatically as a result of a variety of factors, including overfishing, logging, mining, road building, livestock grazing, water diversion, wetland conversion, and dam construction (KRBFTF 1991; NAS 2004; USDOJ and NMFS 2012). Naturally warm water temperatures in parts of the basin have been exacerbated by human modifications to the landscape, resulting in negative impacts to salmon populations and other beneficial uses (KRBFTF 1991; NAS 2004; Bartholow 2005; NCRWQCB 2010). The Arcata Office of the U.S. Fish and Wildlife Service (AFWO) began monitoring water temperatures throughout the lower Klamath basin in the early 2000s because of the importance of water temperatures to salmon and other aquatic species (e.g., lamprey [Meeuwig et al. 2005]; sturgeon [Mayfield and Cech 2004]), along with concern that elevated water temperatures in the Klamath River basin are impairing salmon production.

These water temperature data are used for a variety of purposes, including to develop and validate physical water temperature models (Perry et al. 2011; Jones et al. 2016), drive salmon production models, assess watershed restoration program objectives (Polos 2016), and predict juvenile salmon outmigration timing (Som and Hetrick 2017); among others. This report summarizes Klamath basin water temperature data collected by AFWO in 2016, within the context of the period of record at each location, and evaluates the effects of late-summer to early-fall supplemental releases from Trinity Reservoir on lower Klamath River water temperatures. The specific objectives of this report and associated justifications are as follows:

1. *Describe the water temperature data we collect that are available for use.*

A primary objective of this report is to describe water temperature data collected by AFWO to facilitate their use in future assessments and biological studies. In addition, we conduct a detailed analysis of a subset of the dataset at a set of focal monitoring locations to address objectives two through four.

2. *Evaluate whether numeric water temperature objectives are met on the Trinity River.*

The Klamath River's largest tributary, the Trinity River, is the focus of a large-scale habitat restoration and salmon recovery effort coordinated by the Trinity River Restoration Program (TRRP; <http://www.trrp.net>). The goal of this effort is to restore and maintain the anadromous fishery resources of the Trinity River (USFWS and HVT 1999; USDOJ 2000; USFWS et al. 2000). Populations of salmon and other anadromous fishes in the Trinity River declined dramatically due to the construction of Trinity and Lewiston dams in the 1960s and to large-scale mining, logging, and other human modifications to the watershed (USFWS and HVT 1999; USDOJ 2000; USFWS et al. 2000). One component of the restoration effort is to manage flows out of Trinity and Lewiston dams to improve thermal regimes for all life stages of anadromous salmon that use the mainstem Trinity River. Temperature objectives were developed for holding and spawning adult salmon and for outmigrating juvenile salmon by the Trinity River Flow Evaluation Study (TRFES; Table 1; USFWS and HVT 1999) and were adopted by the Trinity River Mainstem Fishery Restoration Final Environmental Impact Statement/Environmental Impact Report Record of Decision (USDOJ 2000; USFWS et al. 2000). Spring/summer juvenile salmon outmigration temperature objectives differ depending on the water year type for the Trinity River basin, while summer/fall adult salmon temperature objectives are the same regardless of water year type (Table 1). During normal, wet, and extremely wet water years, flows out of Trinity and Lewiston dams are managed to provide optimal thermal conditions throughout the primary juvenile salmon outmigration period. During dry or critically dry water years, flows out of Trinity and Lewiston dams are managed to provide at least marginal thermal conditions for outmigrating juvenile salmon and to facilitate early outmigration.

Table 1. Numeric water temperatures objectives for the Trinity River as defined by the Trinity River Flow Evaluation Study and the Trinity River Mainstem Fishery Restoration Final Environmental Impact Statement/Environmental Impact Report (USFWS and HVT 1999; USFWS et al. 2000).

Water year type	Locations	Period	Days objective is in effect	Temperature objective (mean daily)
<i>Adult salmonid holding and spawning temperature objectives</i>				
All types	Lewiston to Douglas City	July 1 - Sept. 14	92	≤ 15.6
		Sept. 15 - Sept. 30		≤ 13.3
	Lewiston to North Fork Trinity River	Oct. 1 - Dec. 31	92	≤ 13.3
<i>Outmigrant salmonid temperature objectives</i>				
Normal, wet, and extremely wet	Lewiston to Weitchpec	April 1 - May 22	100	< 13.0
		May 23 - June 4		< 15.0
		June 5 - July 9		< 17.0
Dry and critically dry		April 1 - May 22	100	< 15.0
		May 23 - June 4		< 17.0
		June 5 - July 9		< 20.0

3. *Evaluate whether Klamath River water temperatures meet EPA numeric criteria for protection of salmon in the Pacific Northwest.*

A set of numeric water temperature objectives similar to the Trinity River's does not exist for the Klamath River. Instead, we adopted the U.S. Environmental Protection Agency's (EPA) criteria for Pacific Northwest water temperatures to protect Pacific salmon (USEPA 2003; Carter 2006). The EPA prepared these criteria as a set of guidelines for the development of water quality standards by Pacific Northwest states and Native American tribes. By using these criteria we are not asserting any regulatory compliance or lack thereof for the Klamath River. Instead, we use these science-based, peer-reviewed criteria as a measure of the degree to which water temperatures may be impairing Pacific salmon populations in the Klamath River. The primary metric recommended by the EPA for evaluating water temperatures is the seven-day average daily maximum temperature (7DADM), calculated as the average of daily maximum temperatures across a seven-day period. The EPA guidelines also recommend different criteria for different life history stages of Pacific salmon (Table 2; USEPA 2003; Carter 2006). We applied the adult migration (20°C 7DADM) and juvenile rearing (16°C 7DADM) criteria to the Klamath River year round, as there are adults and juveniles of some species of salmon in the river year round (Leidy and Leidy 1984; Shaw et al. 1997). We applied the spawning, incubation, and emergence criteria (13°C 7DADM), to the period of October 1 through April 30, as this is the time period when the vast majority of these reproductive activities occur in the Klamath basin (Leidy and Leidy 1984; Shaw et al. 1997).

4. *Evaluate the efficacy of supplemental late-summer to early-fall flow releases on the Trinity River to reduce water temperatures in the Klamath River and to meet the associated temperature objective.*

In 2002, adult salmon returning to spawn in the Klamath basin suffered a massive die off in the lower Klamath River. The fish kill was attributed to rapidly spreading disease outbreaks of *Ichthyophthirius multifiliis* and *Flavobacterium columnare*, while the root cause was likely a combination of low river flows, high river temperatures, and a large run size of returning adult salmon (Guillen 2003; Belchik et al. 2004; Turek et al. 2004). As a preventative measure to reduce the risk of another disease outbreak and adult fish kill from occurring, supplemental releases of cold water from Trinity Reservoir have been implemented during the late-summer and early-fall adult Chinook salmon migration period in the Klamath basin in 2003, 2004, and 2012-2016. These were years when environmental conditions, disease prevalence, and large forecasted salmon run sizes suggested there was an elevated risk of an adult fish kill. TRRP (2012), Lagomarsino and Hetrick (2013), and Hetrick and Polos (2015) describe the triggering criteria and complete set of objectives for these supplemental releases. In this report we focus specifically on the effect of the supplemental releases on water temperatures in the lower Klamath River downstream of the Trinity River confluence, the target reach of the management action. We evaluate whether the associated water temperature objective (reducing water temperatures in the lower river below a mean daily temperature of 23°C) was met, and use statistical models to evaluate the extent to which Trinity releases reduced water temperatures in the lower Klamath River.



Table 2. EPA criteria for Pacific Northwest water temperatures to protect Pacific salmon. We interpreted these criteria in terms of the EPA recommended metric of seven-day average daily maximum temperatures (7DADM). These criteria were used in our evaluation of Klamath River water temperatures.

Temperature criteria	Period	Life history focus
< 20.0	Year round	Migrating adult salmonids
< 16.0	Year round	Rearing juvenile salmonids
< 13.0	Oct. 1 - April 30	Spawning, incubation, and emergence

## Study Area

The Klamath River basin is the third largest watershed (41,000 km<sup>2</sup>) draining to the Pacific Ocean in the conterminous USA and has an atypical structure compared to most watersheds. The Klamath River originates in the Cascade Mountains of southern Oregon and then flows into the upper Klamath basin, a large, low-relief plateau that historically contained extensive shallow lakes and wetlands (NAS 2004; VanderKooi et al. 2011). The Klamath River then cuts through the southern end of the Cascade Mountains and is impounded by a series of six dams. These dams mark the transition from upper to lower basin, prevent fish passage, alter flow and sediment transport, and degrade downstream water quality in a variety of ways (NCRWQCB 2010). Below the dams, the Klamath River enters the Klamath-Siskiyou Mountains and flows for approximately 235 river kilometers (rkm) to its confluence with the Trinity River. The Trinity River flows through mountainous terrain in a northwesterly direction for 180 rkm from its lower-most dam (Lewiston) to the Klamath River. From the Trinity River confluence, the Klamath River flows for 70 rkm before reaching the Pacific Ocean. In contrast to the upper basin, the lower basin is high relief and the Klamath River and its tributaries primarily flow through confined canyons (NAS 2004; VanderKooi et al. 2011). Overall the watershed has a Mediterranean climate with warm, dry summers and cool, wet winters. However, the climate changes dramatically from east to west and also at finer scales according to elevation, topography, and aspect. The upper basin is generally semi-arid and river flows are primarily driven by snowmelt and groundwater, while the lower basin is more mesic and river flows are primary driven by rainfall and snowmelt (NAS 2004; Williams and Curry 2011).

## Methods

### Data Sources and Protocols

We monitored water temperatures at 30 locations in the Klamath River basin in 2016 and used data from two locations monitored by the U.S. Bureau of Reclamation (Figure 1; Table 3). Of these 32 locations, 16 were on the mainstem Klamath River and 16 were on Klamath River tributaries. Of the 16 tributary locations, 8 were on the mainstem Trinity River. These locations were originally selected to be representative of different reaches of their respective rivers and to not be unduly influenced by local conditions, such as a tributary confluence. All water temperature monitoring locations were situated in the lower Klamath basin except

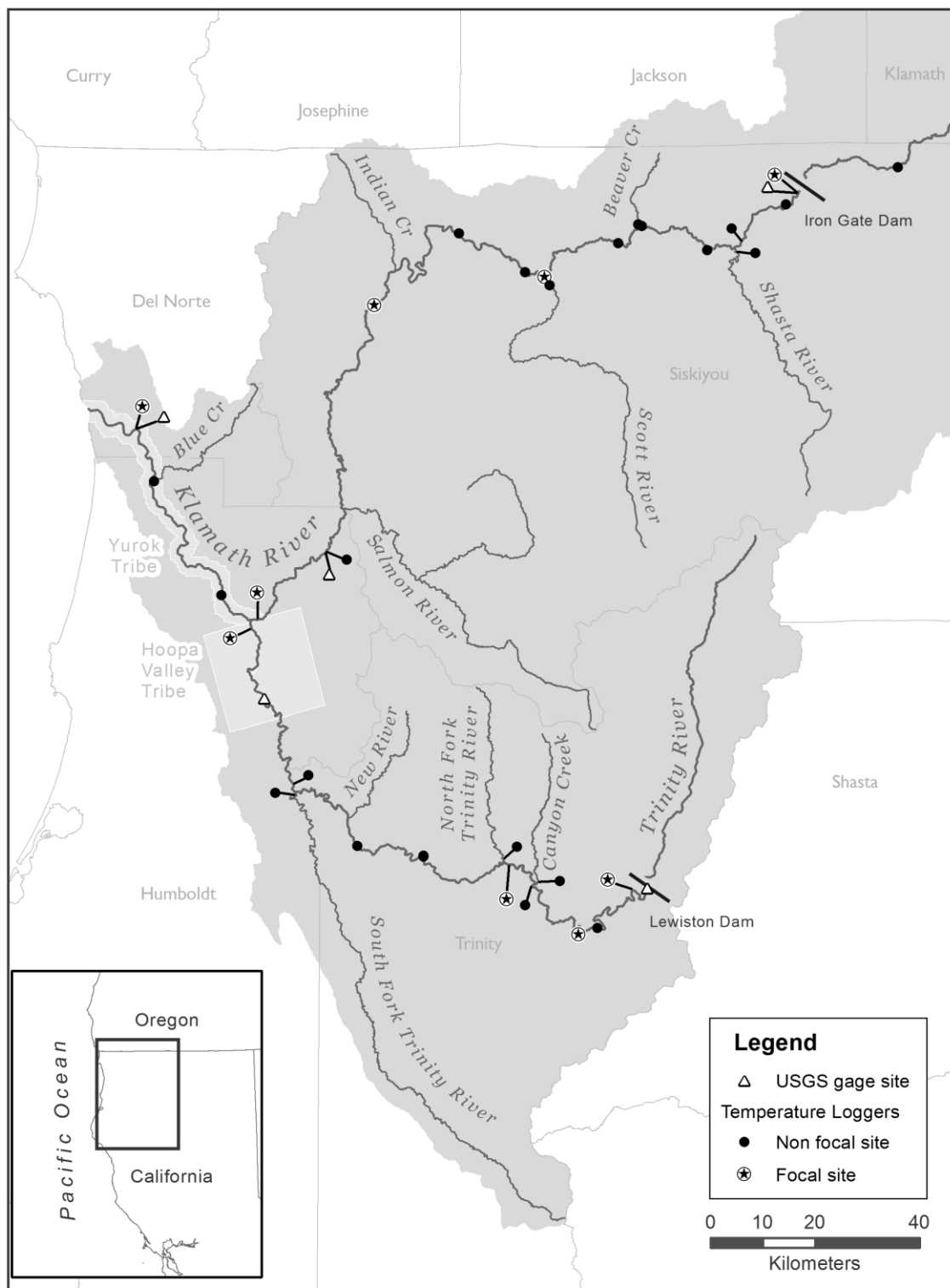


Figure 1. The lower Klamath River basin with the locations that water temperatures were monitored in 2016. Focal sites are the locations analyzed in this report.

Table 3. Klamath River basin locations where water temperatures were monitored by the Arcata Office of the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation in 2016. Only data from focal monitoring sites (highlighted in gray) are reported here, but all data are available upon request. Locations are ordered from upstream to downstream by river kilometer (Rkm) along the Klamath and Trinity rivers, with tributaries arranged where they enter the rivers.

River/Creek	Location	Location Code	Rkm	Latitude	Longitude	Years Operated <sup>†</sup>
Klamath River	Above Copco I	KRCO1	334.3	41.966054	-122.217349	2007-2016
Klamath River	Below Iron Gate Dam	KRIG1	309.7	41.931049	-122.441397	2001-2016
Klamath River	Below R-Ranch	KRRR1	304.3	41.90378	-122.476295	2001-2002, 2005-2016
Klamath River	Above Shasta River	KRSH1	288.5	41.83124	-122.593382	2002-2016
Shasta River	Near mouth	SHKR1	0.8	41.824759	-122.593916	2001-2003, 2005-2016
Klamath River	At Trees of Heaven	KRTH1	281.0	41.825055	-122.658796	2005-2016
Klamath River	Fisher's RV Park	KRBV2	263.4	41.867436	-122.809451	2002-2016
Beaver Creek	Near mouth	BVKR1	0.1	41.870299	-122.817513	2002-2016
Klamath River	At Walker Creek Bridge	KRWB1	254.8	41.837708	-122.864627	2005-2016
Klamath River	Above Scott River	KRSC1	233.2	41.779236	-123.033245	2002-2016
Scott River	At Johnson Bar	SCKR1	2.5	41.765479	-123.022657	2004, 2006-2016
Klamath River	Below Scott River	KRSC2	227.8	41.78791	-123.078927	2005-2016
Klamath River	At Seiad Valley	KRSV1	209.3	41.854087	-123.231469	2001-2016
Klamath River	Below Happy Camp	KRHC1	164.2	41.729647	-123.425579	2002-2016
Klamath River	At Orleans	KROR1	95.5	41.303576	-123.534386	2001-2006, 2008-2016
Klamath River	Above Trinity River	KRWE1	70.2	41.185991	-123.702282	2002-2016
Klamath River	Below Weitchpec	KRBW2	61.7	41.227666	-123.772591	2004, 2007-2016
Klamath River	above Blue Creek	KRBC1	26.2	41.423077	-123.929328	2003-2016
Klamath River	Above mouth	KRTG2	12.7	41.511184	-123.978439	2004-2016
Trinity River	Below Lewiston Dam	TRRR1	173.0	40.720869	-122.829122	2002-2003, 2005-2016
Indian Creek	Near mouth	ICTR1	0.2	40.656452	-122.913884	2002-2016
Trinity River	At Douglas City	DGC*	148.5	40.645278	-122.956665	2005-2016
Trinity River	Above Canyon Creek	TRCN1	127.4	40.731506	-123.056993	2001-2016
Canyon Creek	Near mouth	CNTR1	0.3	40.731906	-123.053819	2001-2016
Trinity River	Above North Fork	NFH*	119.7	40.766532	-123.114479	2005-2016
N.F. Trinity River	Near mouth	NFTR1	0.1	40.770324	-123.127484	2001-2016
Big French Creek	Near mouth	BFTR1	0.1	40.780475	-123.308896	2001-2016
Trinity River	Above Big French Creek	TRBF1	96.8	40.779208	-123.3085	2001-2016
Trinity River	At Burnt Ranch	TRBR1	77.2	40.797284	-123.458798	2001-2016
Trinity River	Above South Fork	TRSF1	50.8	40.88981	-123.602038	2001-2003, 2005-2016
S.F. Trinity River	Near mouth	SFTR1	0.1	40.889434	-123.602214	2001-2016
Trinity River	Above Klamath	TRWE1	0.8	41.181077	-123.705809	2002-2016

\*The locations at Douglas City and above the North Fork on the Trinity River are monitored by the Bureau of Reclamation. These data were obtained from the California data exchange center website (<https://cdec.water.ca.gov/index.html>).

<sup>†</sup>Years operated does not include infilled data.

one, which was located in an un-impounded reach of the mainstem Klamath River upstream of Copco Reservoir within PacifiCorp's Klamath Hydroelectric Project. Data from all AFWO monitoring locations are stored in a Microsoft Access relational database and are available upon request.

At all AFWO monitoring locations, we used digital data loggers (HOBO Water Temp Pro v2, Onset Computer Corporation) and standard protocols (Dunham et al. 2005) to monitor water temperatures. Loggers were set to record at 30-min intervals and were typically swapped out with new loggers twice a year; once in late spring or early summer and once in late fall or early winter. Prior to and after deployment, each logger was tested to verify operation within the manufacturer's accuracy specification of  $\pm 0.2^{\circ}\text{C}$ . The loggers proved accurate and reliable for all tests conducted during the 2016 deployments and no "logger drift" adjustments to temperature data were necessary. Water temperature monitoring in earlier years followed similar protocols, although the type of loggers used and the measurement intervals have changed through time (range: 15 min to 60 min). We downloaded water temperature data for the two U.S. Bureau of Reclamation monitoring locations (Trinity River at Douglas City and Trinity River above the North Fork Trinity) from the California Department of Water Resources California Data Exchange Center (CDEC) website: <https://cdec.water.ca.gov/index.html>. CDEC temperatures were examined for suspicious observations and any data determined to be erroneous were removed.

For this report we focus on four mainstem Trinity River monitoring locations and five mainstem Klamath River monitoring locations (Figure 1). Three of the focal Trinity locations are associated with the downstream extents of different water temperature objectives (above the Klamath, above the North Fork Trinity, and at Douglas City), and the fourth is just downstream of Lewiston Dam, the current upstream extent of anadromy on the Trinity River and the source point for water quality conditions from the upper Trinity basin. The five Klamath River focal locations are below Iron Gate Dam, above the Scott River, below Happy Camp, above the Trinity River (at Weitchpec), and above the mouth (Klamath estuary). Below Iron Gate Dam was chosen as a focal location because it is the current upstream extent of anadromy on the Klamath River and it represents the source point for water quality conditions from the upper Klamath basin. Above the Scott River was chosen because under most conditions, the Scott River is the first tributary that can substantially influence water quality conditions in the Klamath River downstream of Iron Gate Dam. Below Happy Camp was selected because previous monitoring identified this reach as where peak summer water temperatures occur in the mainstem Klamath River downstream of Iron Gate Dam (Magneson 2015). Above the Trinity was chosen because it is upstream of the Klamath's largest tributary and is at a major transition point for the watershed. Above the mouth was chosen as it is the terminus of the river. We focused on the warm half of the year for all summaries and analyses because in the Pacific Northwest that is the period when water temperatures are most likely to negatively impact salmon populations (USEPA 2003). Specifically, we confined this report to data between April 1 and October 31 within a year because exploratory analyses indicated that water temperatures were usually within the optimal range for Pacific salmon outside these dates. Additionally, water temperatures were monitored less consistently outside these dates. Mean daily water temperatures were  $< 13.0^{\circ}\text{C}$  on April 1 at all focal locations in all years, and were  $< 13.0^{\circ}\text{C}$  by October 31 for 65 of 69 Trinity River year by location combinations and for 54 of 76 Klamath River year by location combinations.

## Analyses

To put 2016 water temperatures into the context of the period of record, we compiled previous AFWO and U.S. Bureau of Reclamation water temperature data for the nine focal monitoring locations. The number of years with data varied among the monitoring locations, but 2000 was the earliest year when data were consistently available at some locations. Thus, only data from 2000 and later were incorporated into the temperature summaries. In 2016 and previous years, water temperature time series at some focal locations contained gaps due to the loss of loggers as a result of high flow events or theft, corruption of logger data, or exposure of loggers to air temperatures during low-flow periods. When available, we used data from other loggers at the same or nearby locations to infill time series gaps. Sources of supplemental data include additional AFWO monitoring locations and data collected by the U.S. Forest Service, U.S. Geological Survey (USGS), and the Yurok Tribe Environmental Program. If directly comparable data were not available to infill missing data, but data were available from a relatively nearby monitoring location (maximum distance between locations = 69 rkm), we developed a regression relationship within a season between water temperatures at the two locations to predict water temperatures on missing days at the focal location. Specifically, we used generalized least squares (GLS) regression with a first-order autoregressive correlation structure to account for the temporal nature of the data and the strong thermal inertia of water. The mean percentage of days per location with infilled data was 14.3%, and ranged from 0.2% to 23.4%. The mean root mean square error (RMSE) of infill-regressions of mean daily water temperatures was 0.24°C, and ranged from 0.07°C to 0.59°C. The mean RMSE of infill-regressions of maximum daily water temperatures was 0.37°C and ranged from 0.17°C to 0.77°C.

For each day of the year at each Trinity River focal monitoring location, we calculated the long-term mean, minimum, and maximum of mean daily water temperatures across all years of available data. We implemented identical calculations for the Klamath River focal monitoring locations using 7DADM temperatures instead of mean daily temperatures. These values provided the context (mean and range of observed values) for which to compare 2016 water temperatures. For each focal monitoring location in each year with complete data or sufficient data to encompass the period of time an objective/criterion was exceeded, we calculated the number of days that exceeded the associated water temperature objective/criterion. Finally, for each focal location, we calculated the long-term mean, minimum, and maximum number of days exceeding the associated water temperature objective/criterion across all years.

To evaluate the effect of late-summer to early-fall supplemental flow releases from Trinity Reservoir on lower Klamath water temperatures, we used mean daily water temperatures for August 1 through September 30, in the years 2003, 2004, and from 2012 to 2016 (hereafter referred to as the supplemental flow periods) from five monitoring locations. Four of the locations were focal monitoring locations: Trinity River below Lewiston Dam, Klamath River below Iron Gate Dam, Klamath River above the Trinity River, and Klamath River above the mouth. The fifth location was Klamath River below the Trinity River. We also assembled mean daily flows for the supplemental flow periods from the USGS gaging stations below Lewiston Dam and at Hoopa (~ 20 rkm upstream of the Klamath River) on the Trinity River and below Iron Gate Dam, at Orleans (~ 25 rkm upstream of the Trinity River), and above the mouth on the Klamath River. The temperature and flow data for Iron

Gate and Lewiston dams and the flow data for the Klamath River above the mouth were for visualization purposes while the remaining data were used in analyses.

We evaluated the effects of supplemental flow releases on water temperatures just below the confluence of the Trinity and above the mouth of the Klamath River. Temperature below the Trinity confluence represents the upstream most extent of supplemental flow effects in the Klamath River, while water temperature above the mouth of the Klamath is a management trigger for supplemental flow releases. Because one of the objectives of the supplemental releases was to reduce mean daily water temperatures in the Klamath River below 23°C, as a first step we calculated the number of days before and during the supplemental releases within the supplemental flow period each year that exceeded this objective. Next, we used a series of linear mixed-effects models to quantify the effect of supplemental Trinity releases on Klamath River water temperatures. We developed separate models for the Klamath below the Trinity water temperatures and the Klamath above the mouth water temperatures. Each model included a random intercept of year to account for the fact that water temperatures may vary overall year to year, and within each year we included a first-order autoregressive correlation structure to account for the temporal nature of the data and the strong thermal inertia of water. For each of the two locations we considered a set of three alternative models with increasing levels of complexity. All three models included mean daily water temperatures in the Klamath River above the Trinity as an explanatory variable. These data represent the water temperature inputs from the Klamath River above the Trinity confluence and also reflect changing meteorological conditions during the period of interest that will affect lower Klamath River water temperatures. The first model only contained this explanatory variable. The second model also contained mean daily flows at the Trinity River Hoopa USGS gage with a one day lag as an explanatory variable to represent the influence of Trinity River flows on Klamath River water temperatures. The one-day lag was included to account for the travel time from the Hoopa gage to the Klamath River downstream of the Trinity River confluence. In addition to the two variables above, the third model also included mean daily flows at the Klamath River at Orleans USGS gage with a one-day lag. These data were included to represent the potential mediating influence of Klamath River flows on the extent to which Trinity River inputs affect lower Klamath River water temperatures. We evaluated evidence for these three competing models using Akaike's information criterion (AIC) and AIC weights. All analyses were performed using the R software for statistical computing (R Core Team 2015). The GLS regressions and linear mixed-effects models were implemented using the nlme R package (Pinheiro et al. 2017).

## Results

### Trinity River

In 2016, designated a wet water year, the Trinity River at Douglas City water temperature objective was exceeded during 14 days, which was greater than the number of days the objective was exceeded at this location for 10 of 12 previous years (Figure 2; Appendix A). The Trinity River above the North Fork Trinity River objective was exceeded during 3 days, which was greater than the number of days the objective was exceeded at this location for 7 of 11 previous years. The Trinity River above the Klamath objective was exceeded during 52 days, which was greater than the number of days the objective was exceeded at this

location for 12 of 15 previous years. Water temperatures at the focal Trinity River monitoring locations for 2000-2015 are found in Appendix B.

### **Klamath River**

In 2016, the number of days exceeding the migrating adult salmon EPA 7DADM criterion at focal Klamath River monitoring locations ranged from 86 days (above the mouth) to 104 days (above the Scott River) (Figure 3; Table 4; Appendix C). These numbers of days exceeding the migrating adult salmon criterion were all greater than the long-term means for these locations. The number of days exceeding the rearing juvenile salmon EPA 7DADM criterion ranged from 141 days (above the mouth) to 156 days (below Iron Gate Dam). These numbers of days exceeding the rearing juvenile salmon criterion were also all greater than the long-term means for these locations. The number of days exceeding the spawning, incubation, and emergence EPA 7DADM criterion ranged from 23 days (above the Trinity) to 50 days (above the Scott River). The number of days exceeding the criterion for the Klamath above the Trinity River was the fewest days observed at this location across all years while the number of days exceeding the criterion for the Klamath below Iron Gate Dam was the most days observed at this location across all years. The number of days exceeding the criterion for the Klamath above Scott was also greater than its long-term mean, while the number of days exceeding the criterion for the Klamath below Happy Camp and the Klamath above the mouth were below their respective long-term means. 7DADM water temperatures at the focal Klamath River monitoring locations for 2000-2015 are found in Appendix D.

### **Water temperature effects of supplemental flow releases**

During the Trinity Reservoir supplemental flow periods, mean daily water temperatures were almost exclusively below 23°C at both the Klamath below the confluence with the Trinity River and the Klamath above the mouth once supplemental flows reached the Klamath River (Table 5). The only exception was in 2012, when mean daily water temperatures exceeded 23°C below the confluence of the Trinity River during the first two days of supplemental releases.

### ***Supplemental flow release effects above the mouth of the Klamath River***

The best-supported model of supplemental flow period mean daily water temperatures above the mouth of the Klamath River included the variables water temperature in the Klamath River above the Trinity and Trinity River flow at Hoopa (Table 6). This model fit the data well (Figure 4), with an RMSE of 0.47°C. The second ranked model additionally included Klamath River flow at Orleans. This model had slightly less support than the top model. The third ranked model only included water temperature in the Klamath above the Trinity. This model had substantially less support than the top two models. The coefficients from both models that included Trinity flows indicated that an increase of 1000 ft<sup>3</sup>/s in Trinity River flow at Hoopa would result in a mean water temperature decrease of 0.37°C above the mouth of the Klamath River. See Figure 4 and Appendix E for visualization of the effects of Klamath River water temperatures above the confluence with the Trinity and Trinity River flows at Hoopa on water temperatures above the mouth of the Klamath.

***Supplemental flow release effects below the confluence of the Trinity River***

The best-supported model of supplemental flow period mean daily water temperatures below the confluence of the Trinity included the variables water temperature in The Klamath River above the Trinity, Trinity River flow at Hoopa, and Klamath River flow at Orleans (Table 7). This model fit the data well (Figure 5), with an RMSE of 0.33°C. The second ranked model included water temperatures in the Klamath above the Trinity and Trinity River flow at Hoopa. The third ranked model only included water temperatures in the Klamath above the Trinity. Both the second and third ranked models had considerably less support than the top model. The coefficients from both models that included Trinity flows indicated that an increase of 1000 ft<sup>3</sup>/s in Trinity River flow at Hoopa would result in a mean water temperature decrease of 0.9°C below the confluence of the Trinity River. See Figure 5 and Appendix E for visualization of the effects of Klamath River water temperatures above the confluence with the Trinity and Trinity River flows at Hoopa on water temperatures below the confluence of the Trinity River.



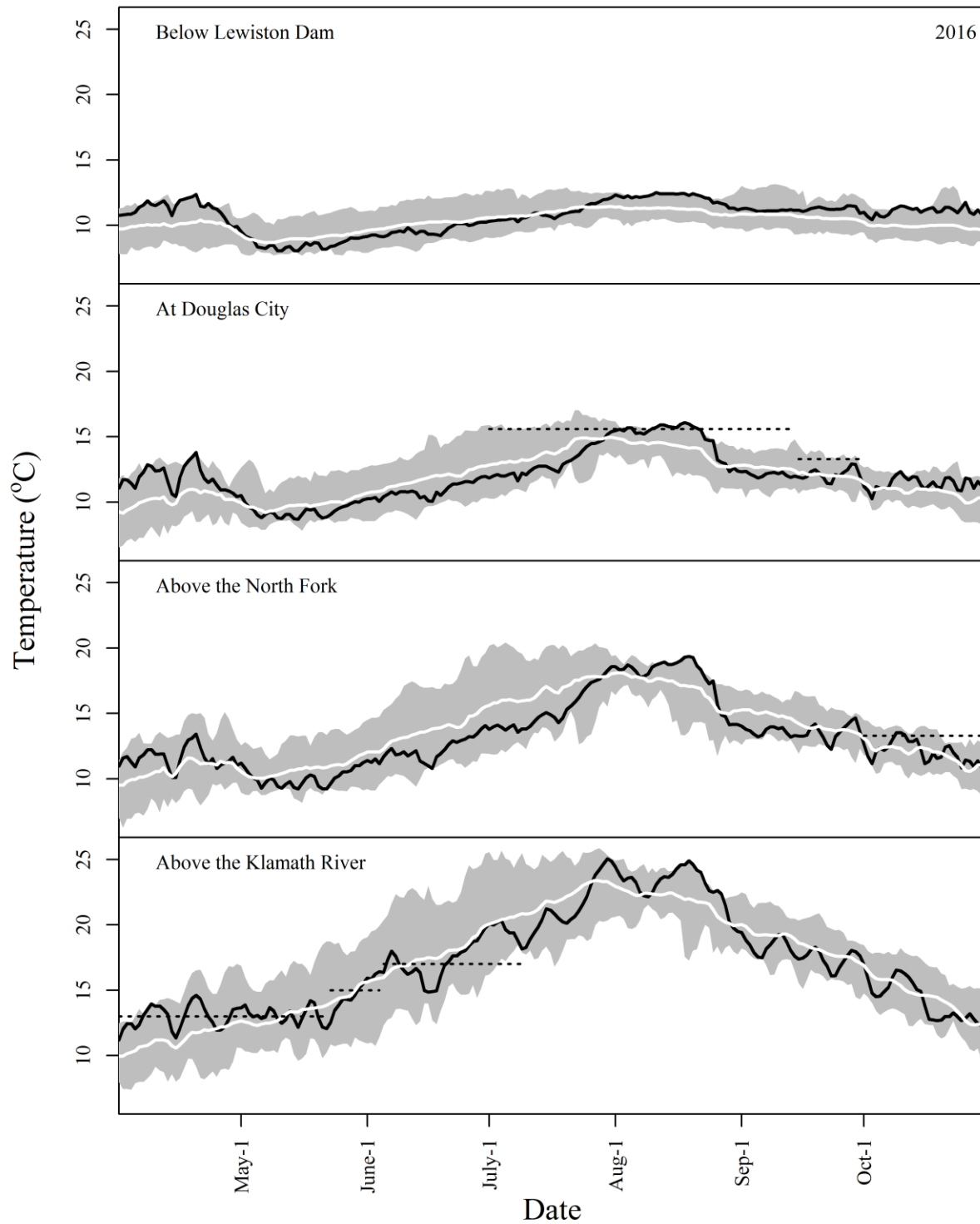


Figure 2. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2016, with historical conditions. Black line = mean daily water temperatures in 2016; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

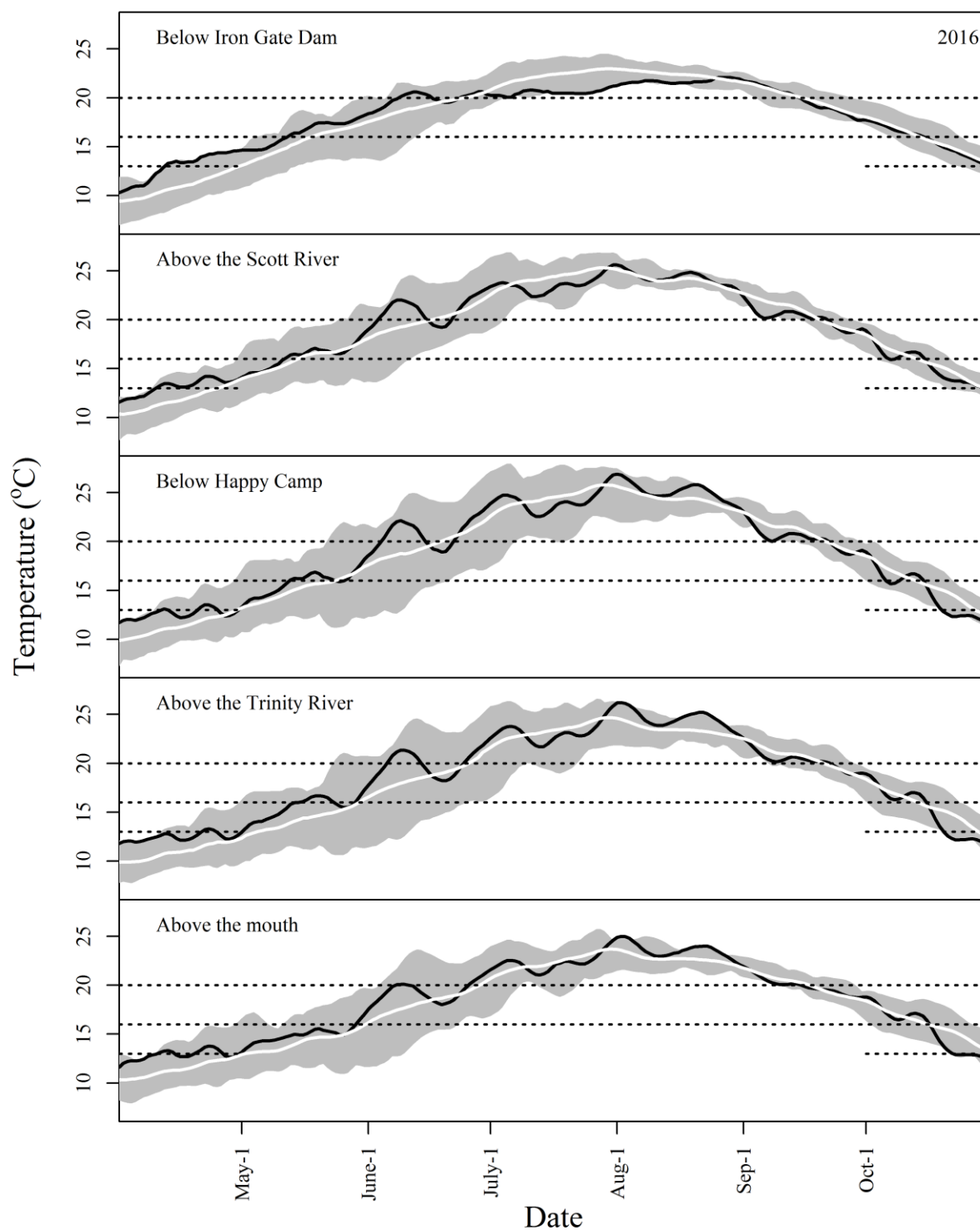


Figure 3. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2016, with historical conditions. Black line = 7DADM water temperatures in 2016; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

Table 4. The number of days exceeding the seven-day average daily maximum (7DADM) EPA criteria for Pacific Northwest water temperatures to protect Pacific salmon at five Klamath River focal monitoring locations in 2016. The numbers in parentheses are the mean, minimum, and maximum number of days exceeding the water temperature criteria across the period of record for each location, respectively. KRIG = Klamath below Iron Gate Dam; KRSC1 = Klamath above the Scott River; KRHC1 = Klamath below Happy Camp; KRWE1 = Klamath above the Trinity River; KRTG2 = Klamath above the mouth. Bolded numbers denote record values.

Location	Rkm	Adult migration: 20°C 7DADM	Juvenile rearing: 16°C 7DADM	Spawning, incubation, and emergence: 13°C 7DADM
KRIG1	309.7	91 (86.3, 74-102)	156 (149.1, 129-163)	<b>49</b> (34.0, 26-49)
KRSC1	233.2	104 (99.0, 83-120)	155 (147.8, 128-175)	50 (35.8, 25-52)
KRHC1	164.2	103 (98.6, 73-128)	149 (140.2, 116-176)	26 (31.4, 25-51)
KRWE1	70.2	99 (91.8, 63-119)	149 (137.9, 110-176)	<b>23</b> (31.0, 23-44)
KRTG2	12.7	86 (84.5, 64-110)	141 (137.4, 118-171)	33 (34.0, 27-51)

Table 5. Number of days when mean daily water temperatures reached or exceeded 23°C during the supplemental flow periods in the Klamath River below the confluence with the Trinity and in the Klamath River above the mouth. Days are divided between before and during supplemental releases from Trinity Reservoir.

Year	Klamath below the Trinity River		Klamath above the mouth	
	Days ≥ 23°C prior to releases	Days ≥ 23°C during releases	Days ≥ 23°C prior to releases	Days ≥ 23°C during releases
2003	6	0	2	0
2004	18	0	7	0
2012	10	2	4	0
2013	3	0	1	0
2014	18	0	6	0
2015	2	0	1	0
2016	19	0	13	0

Table 6. Ranking of models evaluating the effect of late-summer to early-fall supplemental releases from Trinity Reservoir on water temperatures above the mouth of the Klamath River. WE.temp = Mean daily water temperatures in the Klamath River above the Trinity; Hoopa = Mean daily flow of the Trinity River at Hoopa; Orleans = Mean daily flow of the Klamath River at Orleans; lag = one day lag.

Model	Δ AIC	AIC weight
5.7750 + 0.7206*WE.temp - 0.00037*Hoopa.lag	0.0	0.71
5.5804 + 0.7260*WE.temp - 0.00037*Hoopa.lag + 0.00005*Orleans.lag	1.8	0.29
7.2387 + 0.6346*WE.temp	29.9	<0.001

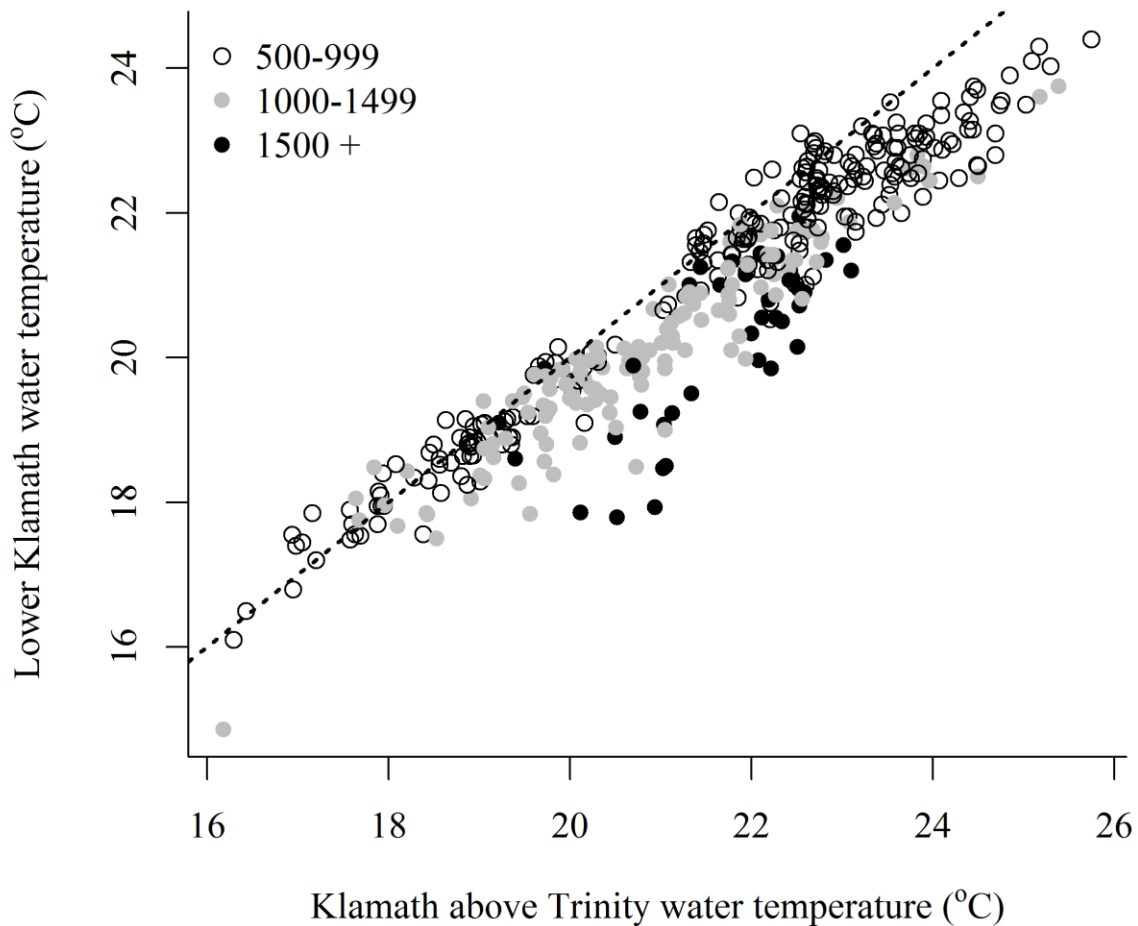


Figure 4. Mean daily water temperatures in the Klamath River above the mouth as a function of mean daily water temperatures in the Klamath River upstream of the Trinity River during the supplemental flow periods. Point colors and symbols correspond to the one-day lagged mean daily flow of the Trinity River at Hoopa. The dotted line is the 1:1 line.

Table 7. Ranking of models evaluating the effect of late-summer to early-fall supplemental releases from Trinity Reservoir on water temperatures in the Klamath River below the Trinity River. WE.temp = Mean daily water temperatures in the Klamath River above the Trinity; Hoopa = Mean daily flow of the Trinity River at Hoopa; Orleans = Mean daily flow of the Klamath River at Orleans; lag = one day lag.

Model	$\Delta$ AIC	AIC weight
$0.9578 + 0.9595 \cdot \text{WE.temp} - 0.00090 \cdot \text{Hoopa.lag} + 0.00020 \cdot \text{Orleans.lag}$	0.0	0.98
$1.5394 + 0.9473 \cdot \text{WE.temp} - 0.00089 \cdot \text{Hoopa.lag}$	8.0	0.02
$1.3617 + 0.9163 \cdot \text{WE.temp}$	462.1	<0.001

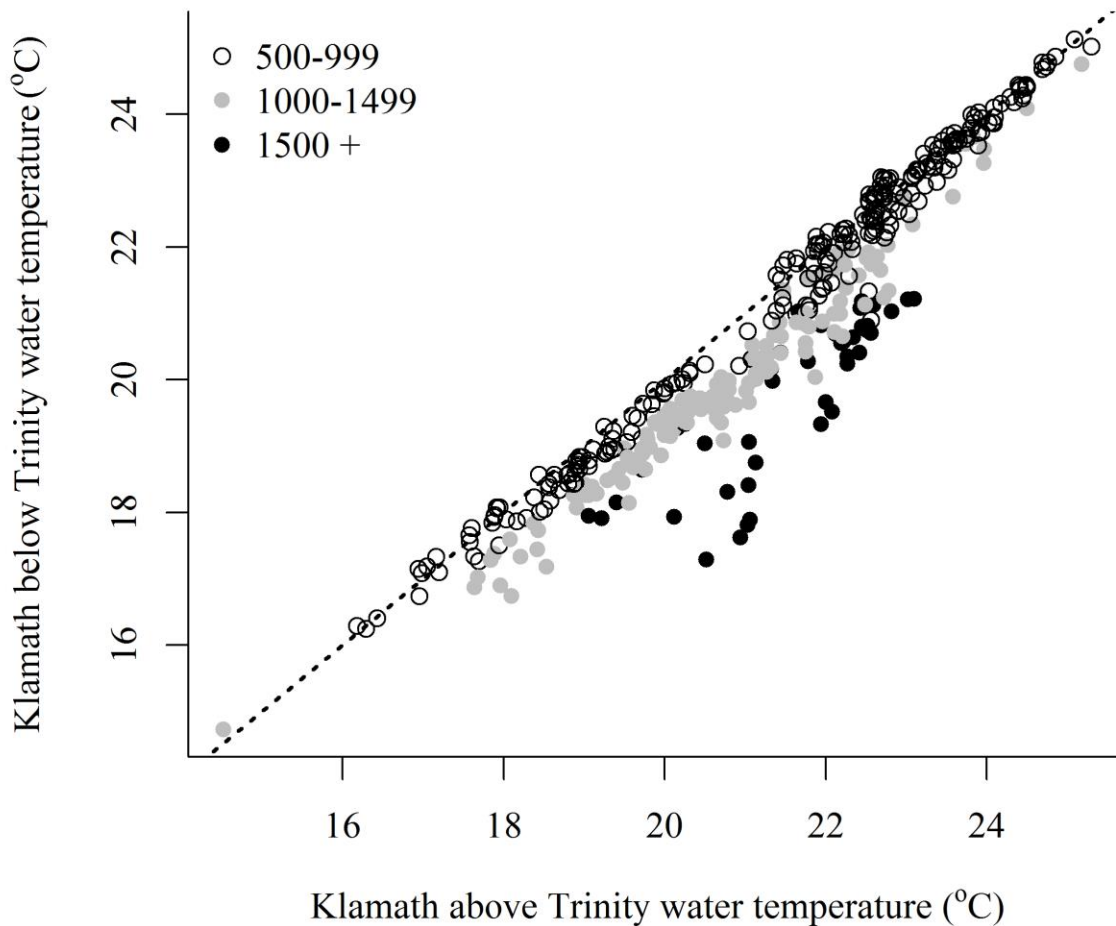


Figure 5. Mean daily water temperatures in the Klamath River below the confluence with the Trinity as a function of mean daily water temperatures in the Klamath River upstream of the Trinity River during the supplemental flow periods. Point colors and symbols correspond to the one-day lagged mean daily flow of the Trinity River at Hoopa. The dotted line is the 1:1 line.

## Discussion

### Trinity River

In 2016, water temperature objectives for the Trinity River were exceeded at the downstream points of the different objectives. The numbers of days exceeding the objectives were greater than the long-term average number of days exceeding the objectives at two of the three monitoring locations. Possible drivers of these warmer water temperatures include a reduced cold water pool volume in Trinity Reservoir due to multiple preceding years of drought, warm spring air temperatures, and below average snowpack for the 2016 water year. While Northern California precipitation overall was generally at or above average for the water year, much of the precipitation fell as rain, minimizing the

cooling effect of snowmelt during the summer months. More generally, in all but one year (2008), temperature objectives for emigrating salmonids were exceeded for at least 7 days above the confluence with the Klamath River, with a maximum exceedance of 65 days in 2015. These results suggest the TRRP should consider revising management approaches to meet the water temperature objective and/or formally clarify the prioritization of the use of Trinity River flows to achieve multiple ecological objectives.

In addition to temperature objectives, TRRP water allocations from Trinity Reservoir are managed to achieve other objectives related to river restoration and the recovery of salmon populations. These additional objectives include mimicking natural high flow-events to create geomorphic change, promoting the recruitment of woody riparian plant species, and maintaining microhabitat conditions that meet the requirements for multiple salmonid life stages (USFWS and HVT 1999). While these objectives are often achieved in concert, at times managing flows to achieve one objective may reduce the ability to achieve other objectives. During the period evaluated in this report, TRRP adaptive management prioritized achieving other flow-related ecological objectives over the water temperature objectives (Joe Polos, AFWO, personal communication). Because of the frequent exceedance of the emigrating salmonid water temperature objective in recent years, it may be worthwhile for the TRRP to formally clarify the justification for the current prioritization of achieving flow-related ecological objectives.

Water temperature objectives were exceeded less often at the two monitoring locations within the restoration reach of the Trinity River (Lewiston Dam to the North Fork Trinity), suggesting that exceedance of objectives at the mouth of the Trinity may be due at least in part to impairments to other portions of the watershed or external forcing outside the TRRP's control (e.g., regional weather or climate). However, our descriptive analysis did not address the reasons for the frequent exceedance of objectives observed in this study. An investigation into causal factors associated with exceedances may support the refinement of management approaches to better align thermal regimes within the bounds of existing temperature objectives.

## **Klamath River**

The numbers of days exceeding the migrating adult salmon and rearing juvenile salmon EPA criteria in 2016 were greater than the respective long-term averages at all five Klamath River focal monitoring locations. These results indicate that overall 2016 water temperatures were warmer than average for the period of April through October. In 2016 and for the long-term averages, the migrating adult salmon and rearing juvenile salmon criteria were exceeded approximately three months and greater than four months, respectively, at all five focal monitoring locations. These results are further evidence that elevated warm-season water temperatures are a factor limiting the size of salmon populations, the expression of salmon life history types (e.g., river-type Chinook Salmon) and likely the population sizes of other native cold-water fishes in the Klamath basin (KRBFTF 1991; NAS 2004; Bartholow 2005; NCRWQCB 2010; NMFS 2014). However, the impact of high summer water temperatures will vary depending on the timing and extent of the freshwater stage of anadromous species' life histories.

It is important to note that the Klamath basin's moderate latitude (~42°N) and the extensive wetlands and shallow lakes in the upper basin likely result in naturally elevated summer

water temperatures in some parts of the basin relative to nearby coastal watersheds (Bartholow 2005; NCRWQCB 2010) or rivers located in more northern latitudes. However, we should be cautious about attributing the high water temperatures observed in the Klamath River to natural causes. The myriad of anthropogenic modifications to the watershed have generally exacerbated naturally warm summer water temperatures. Logging, mining, grazing, diversion of water for agriculture and other uses, draining of wetlands, construction of roads, and depletion of beaver populations, among other activities, have all contributed to increased warm-season water temperatures in the basin (KRBFTF 1991; NAS 2004; NCRWQCB 2010). The mainstem Klamath River dams also affect water temperatures. While their overall influence is complex, the dams generally decrease water temperatures slightly during spring and early summer, increase water temperatures during late summer and fall, and dampen diel temperature fluctuations (Bartholow 2005; NCRWQCB 2010; Perry et al. 2011; USDOI and NMFS 2012).

The record high number of days exceeding the spawning, incubation, and emergence criterion below Iron Gate Dam in 2016 may have been the result of hydro-meteorological conditions. We used data from a downstream temperature monitoring location during the spring to infill 83 days of missing data at the Below Iron Gate Dam location. These temperatures may have been warmer than temperatures directly below Iron Gate Dam. However, the infilled data were only collected about 2 km downstream of the below Iron Gate Dam location, so any differences should be minimal. Instead, April regional air temperatures were warmer in 2016 than during any of the previous 16 years. Additionally, after high flows in late winter and early spring, mean daily flows out of Iron Gate dam were reduced below average in April. The combination of unusually high air temperature and below average flows out of Iron Gate Dam may have been the cause of the record number of days exceeding the criterion at this location. April water temperatures were also above average at the above the Scott River location, further suggesting these warm temperatures were not artifacts of using data from another location. The below average number of days exceeding (a record low for the Klamath above the Trinity location) the spawning, incubation, and emergence criterion for the three downstream focal Klamath locations were likely due in part to the earlier than normal arrival of cool, wet storms in October 2016. Regional October air temperatures were cooler than during any of the previous 16 years.

In this report we adopted EPA temperature criteria developed to provide for the protection of salmonids in the U.S. Pacific Northwest. As part of the development of these criteria, EPA compiled the results of studies of salmonids and water temperature from throughout the range of Pacific salmon. In their synthesis of existing information, EPA found little evidence of important population-level variation in water temperature tolerance for Pacific salmon species (McCullough et al. 2001). More recently, however, studies have documented population-level adaptation to local thermal regimes (Eliason et al. 2011; Narum et al. 2013). We are not aware of any studies that have demonstrated genetic adaptation of salmon populations within the Klamath basin to local thermal regimes, although Strange (2010) presented limited evidence that Klamath fall Chinook Salmon have higher thermal tolerances than other Chinook Salmon populations. However, behavioral thermoregulation of salmon by exploiting spatial and temporal thermal refugia in the Klamath basin is well documented (e.g., Sutton et al. 2007; Strange 2010; Sutton and Soto 2012; Brewitt and Danner 2014). Regardless of the potential for adaptation to local thermal regimes, water temperature is of primary management concern for the restoration of salmon and other

native aquatic species in the Klamath basin, and current water temperatures impair multiple beneficial uses (NCRWQCB 2010).

### **Water temperature effects of supplemental flow releases**

While many anthropogenic modifications to river ecosystems contribute to increased summer water temperatures, large storage reservoirs with water release points situated below the reservoir surface layer can moderate the temperature of their releases (Poole and Berman 2001). This is the case with Trinity Reservoir, which can modulate downstream water temperatures by varying release volumes of cold water and by varying the release point from the reservoir. Our analysis of late-summer to early-fall water temperatures during the seven years when supplemental releases occurred suggested that these releases have generally succeeded at achieving their water temperature objectives. Once releases arrived in the lower Klamath River, mean daily temperatures nearly always dropped below the associated objective of 23°C. Additionally, our statistical models indicated that releases resulted in a mean reduction of approximately 0.9°C just downstream of the confluence with the Trinity per increase of 1000  $\text{ft}^3/\text{s}$  in Trinity River flows, and a mean reduction of approximately 0.4°C above the mouth per increase of 1000  $\text{ft}^3/\text{s}$  in Trinity River flows. The best supported model of water temperatures at these two locations both included Trinity River flow as a variable. The most supported model of water temperatures just downstream of the confluence with the Trinity also included Klamath River flow at Orleans, which had a small positive (i.e., warming) effect in the model. However, caution is needed when interpreting this parameter. It does not mean that increasing flow in the Klamath above the confluence with the Trinity will result in increased water temperatures in the lower Klamath River. Instead, greater flows in the Klamath will moderate the effect of Trinity River water temperatures. Klamath River flow at Orleans was included in the second-ranked model of temperatures above the mouth of the Klamath. This model only differed from the top model by 1.8 AIC, indicating little difference in the likelihoods of the top-ranked and second-ranked models (Arnold 2010). Similarly, the coefficient for the Klamath flow parameter in the second-ranked model was essentially zero (0.05°C increase per 1000  $\text{ft}^3/\text{s}$  increase), further suggesting little explanatory power of the Klamath flow parameter.

Previous assessments have found that the late-summer to early-fall supplemental releases had a cooling effect on lower Klamath water temperatures (e.g., Zedonis 2004, 2005). While our results and these earlier analyses indicate that supplemental releases from Trinity Reservoir have been successful in cooling lower Klamath River water temperatures, at least modestly, one point of caution is warranted. Because the supplemental releases occurred around the same time each year, our results may not necessarily apply to other times of year when hydro-meteorological conditions in the basin differ from those of late summer and early fall. While our models explicitly incorporated the input of upstream Klamath River temperatures and changing meteorological conditions, the effect of increased Trinity River flows at other times of year may be different than the effect estimated by our models (Zedonis 2004, 2005). An alternative approach to quantifying the effect of the supplemental releases on lower Klamath water temperatures would be to use the physically-based RBM10 water temperatures models developed for the Klamath and Trinity rivers (Perry et al. 2011; Jones et al. 2016). Many of the water temperature data included in this report were used in the calibration of these models, which can be employed as forecasting tools to help determine if supplemental releases are necessary to achieve water temperature objectives



(Hetrick and Polos 2015; Jones et al. 2016). Although beyond the scope of this report, we recommend that future assessments of supplemental flow period water temperatures compare the performance of our statistical models to the performance of the Klamath and Trinity RBM10 models under these unique conditions.

We recommend that future assessments of the supplemental releases monitor possible impacts to other native aquatic fauna. While cool, wet storms occasionally occur in the late summer or early fall in Northern California, large, rapid injections of cold water in the Trinity River are probably not phenomena that native aquatic species are adapted to during summer in this region. While the releases successfully cooled water temperatures and may have played a role in preventing disease outbreaks and adult fish kills, a more sustainable approach may be the restoration of natural watershed attributes and the reduction of the numerous water withdrawals in the basin to maintain higher summer flows and lower summer water temperatures overall, reducing the need for emergency releases from Trinity Reservoir.

## **Conclusion**

To summarize, in the Klamath River and lower portions of the Trinity River, water temperatures have frequently been higher than the values recommended to protect salmon populations. In the restoration reach of the Trinity River (upstream of the North Fork Trinity River), cold-water releases have typically kept water temperatures from reaching stressful levels. Additionally, supplemental releases from Trinity Reservoir in the late summer and early fall have successfully cooled water temperatures in the lower Klamath River, reducing the risk of adult fish kills. However, watershed restoration and changes to water management are likely necessary to reduce summer water temperatures and to ensure the viability of imperiled salmon populations in the basin. Finally, we hope this report can serve as a template and foundation for future reports and analyses of drivers of water temperatures in the Klamath River basin.

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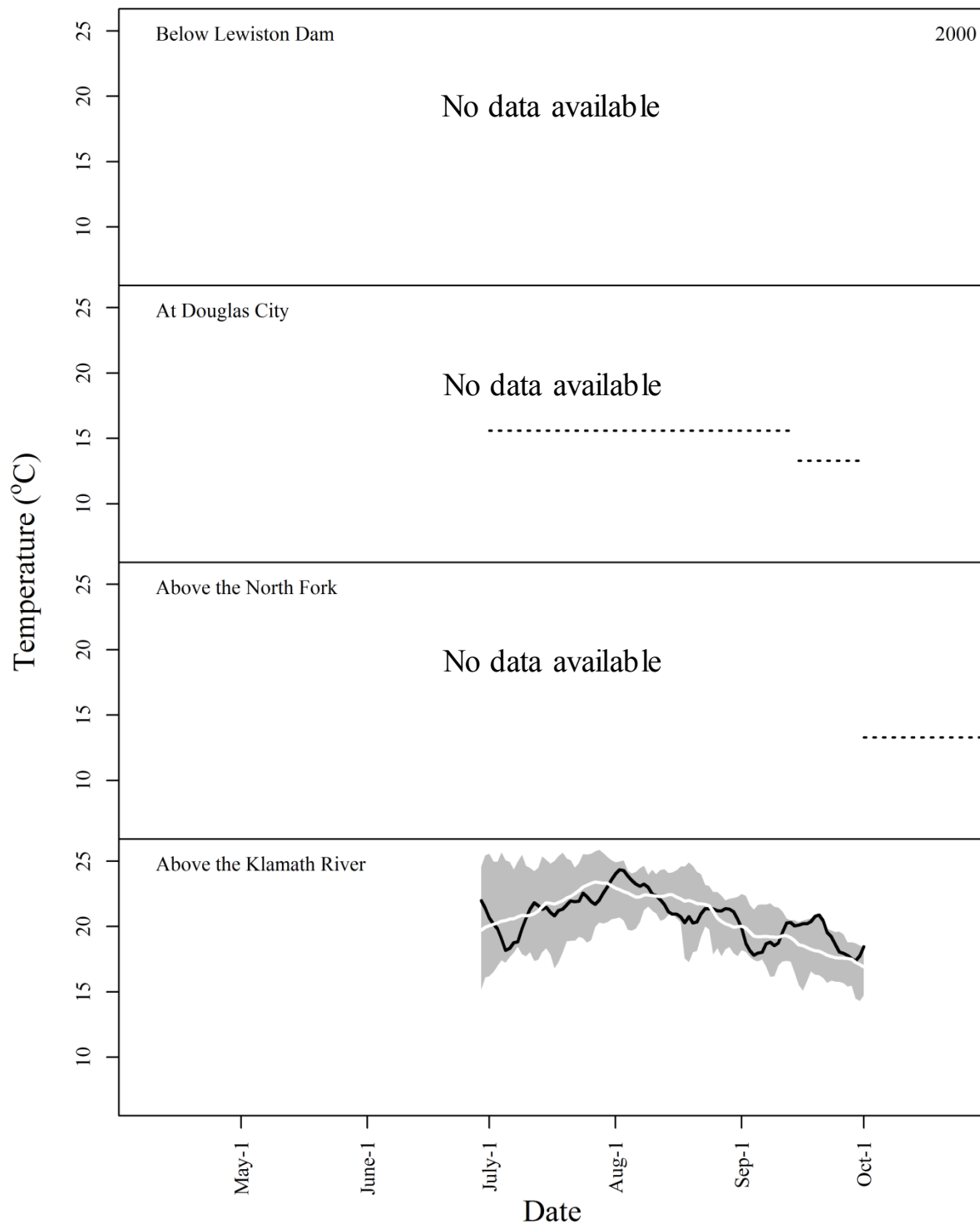
Appendix A. Number of days exceeding numeric water temperature objectives for the three specified locations on the Trinity River, 2001-2016. DGC = Trinity at Douglas City; NFH = Trinity above the North Fork Trinity; TRWE1 = Trinity above the Klamath.

Year	Objective locations			Forecast	Actual
	DGC	NFH	TRWE1	water year type	water year type
2001	--	--	33 <sup>a</sup>	Dry	Dry
2002	0	--	54	Normal	Normal
2003	11	--	34	Wet	Wet
2004	0	--	43	Wet	Wet
2005	--	1	21 <sup>b</sup>	Normal	Wet
2006	6	0	18	Ex. Wet	Ex. Wet
2007	3	0	19	Dry	Dry
2008	1	4	0	Normal	Dry
2009	31	2	21	Dry	Dry
2010	6	7	10	Normal	Wet
2011	0	0	7	Wet	Wet
2012	0	1	25	Normal	Normal
2013	0	0	26	Dry	Dry
2014	18	15	53	Crit. Dry	Crit. Dry
2015	--	18	65	Dry	Dry
2016	14	3	52	Wet	Wet

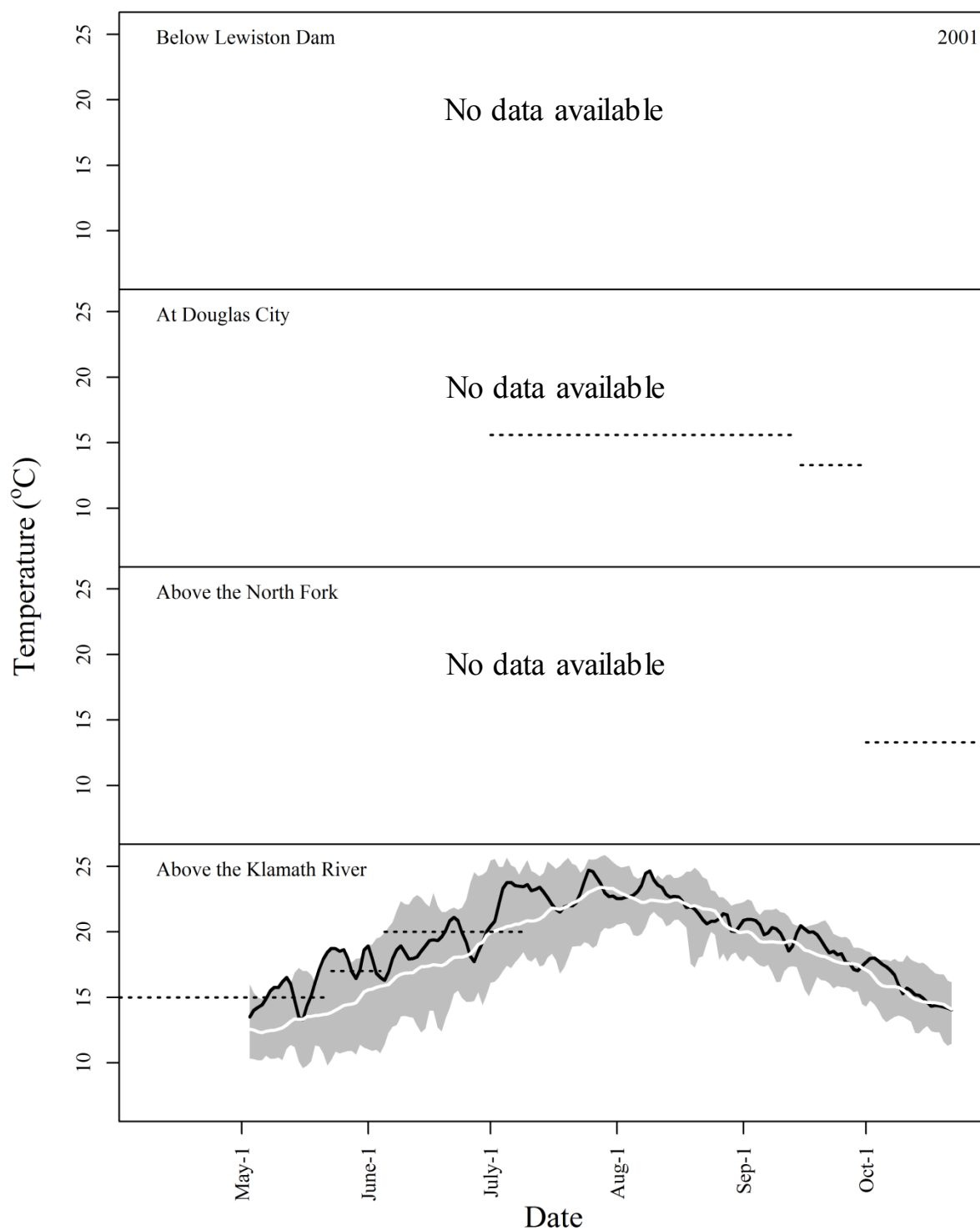
<sup>a</sup> Data unavailable prior to 5/3 for TRWE1 in 2001. We assumed mean daily temperatures did not reach or exceed 15.0 C before this date.

<sup>b</sup> Data unavailable prior to 4/4 for TRWE1 in 2005. We assumed mean daily temperatures did not reach or exceed 13.0 C before this date.

Appendix B. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2000-2015, with historical conditions. Includes both observed and infilled water temperatures.

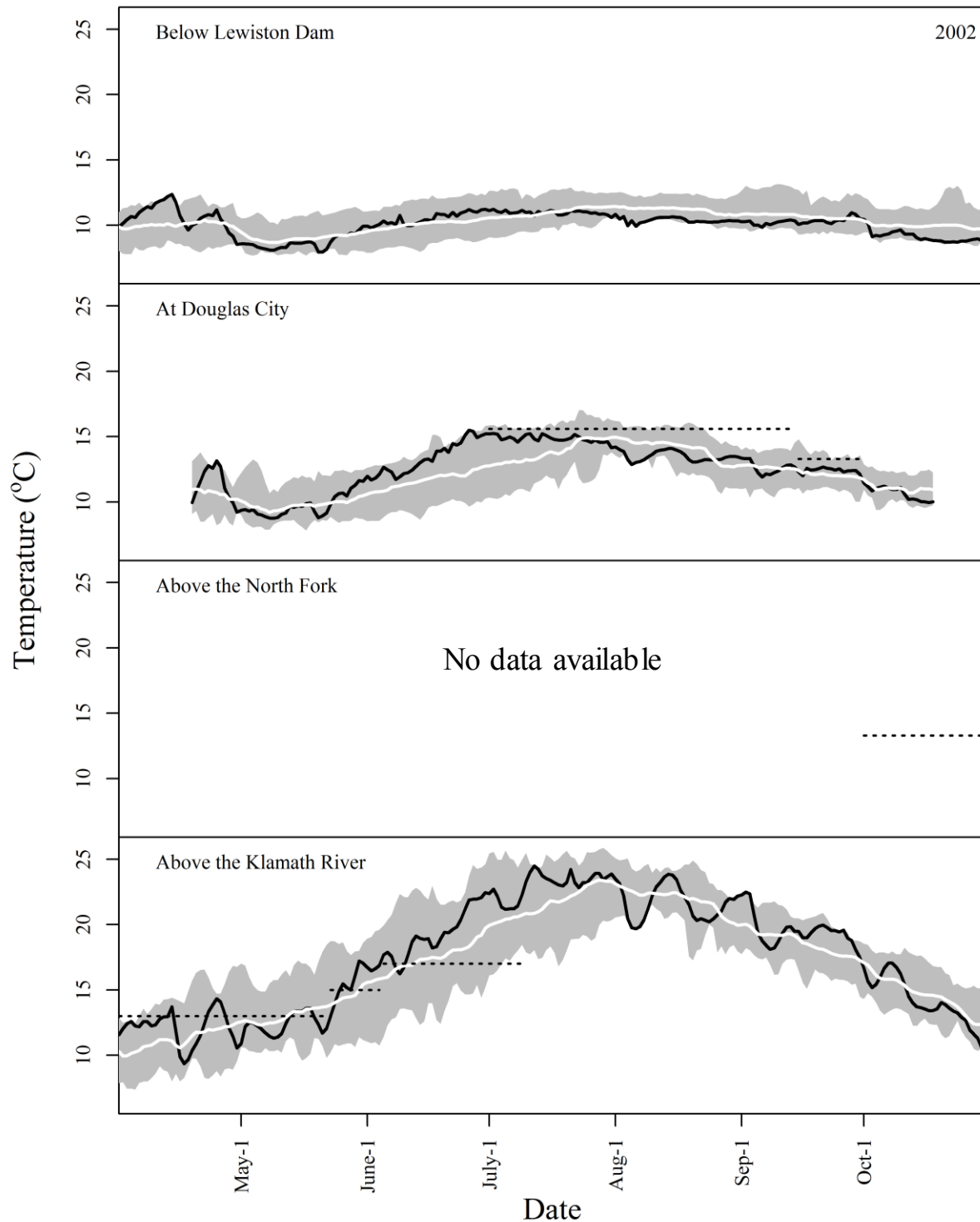


Appendix B1. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2000, with historical conditions. Black line = mean daily water temperatures in 2000; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

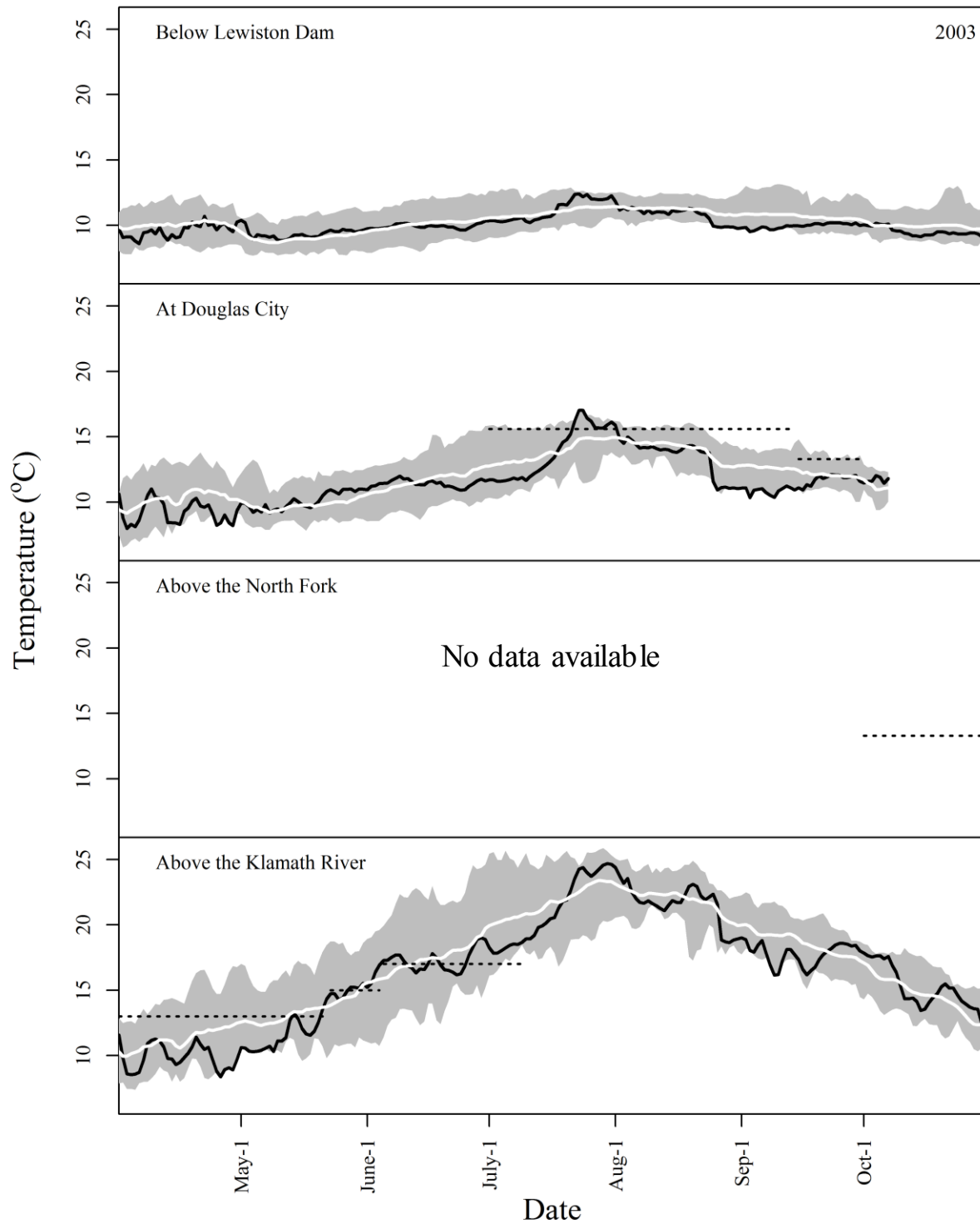


Appendix B2. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2001, with historical conditions. Black line = mean daily water temperatures in 2001; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

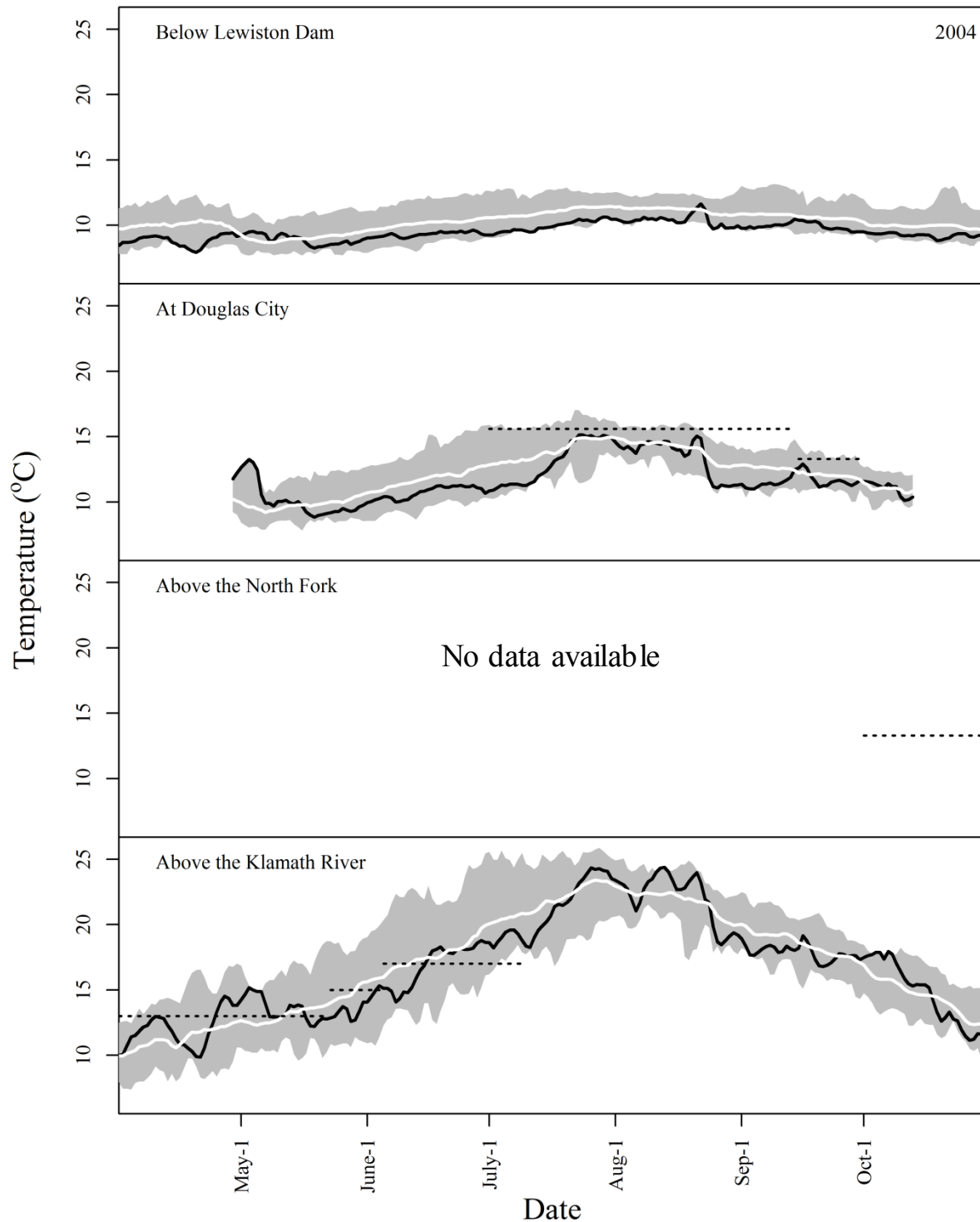




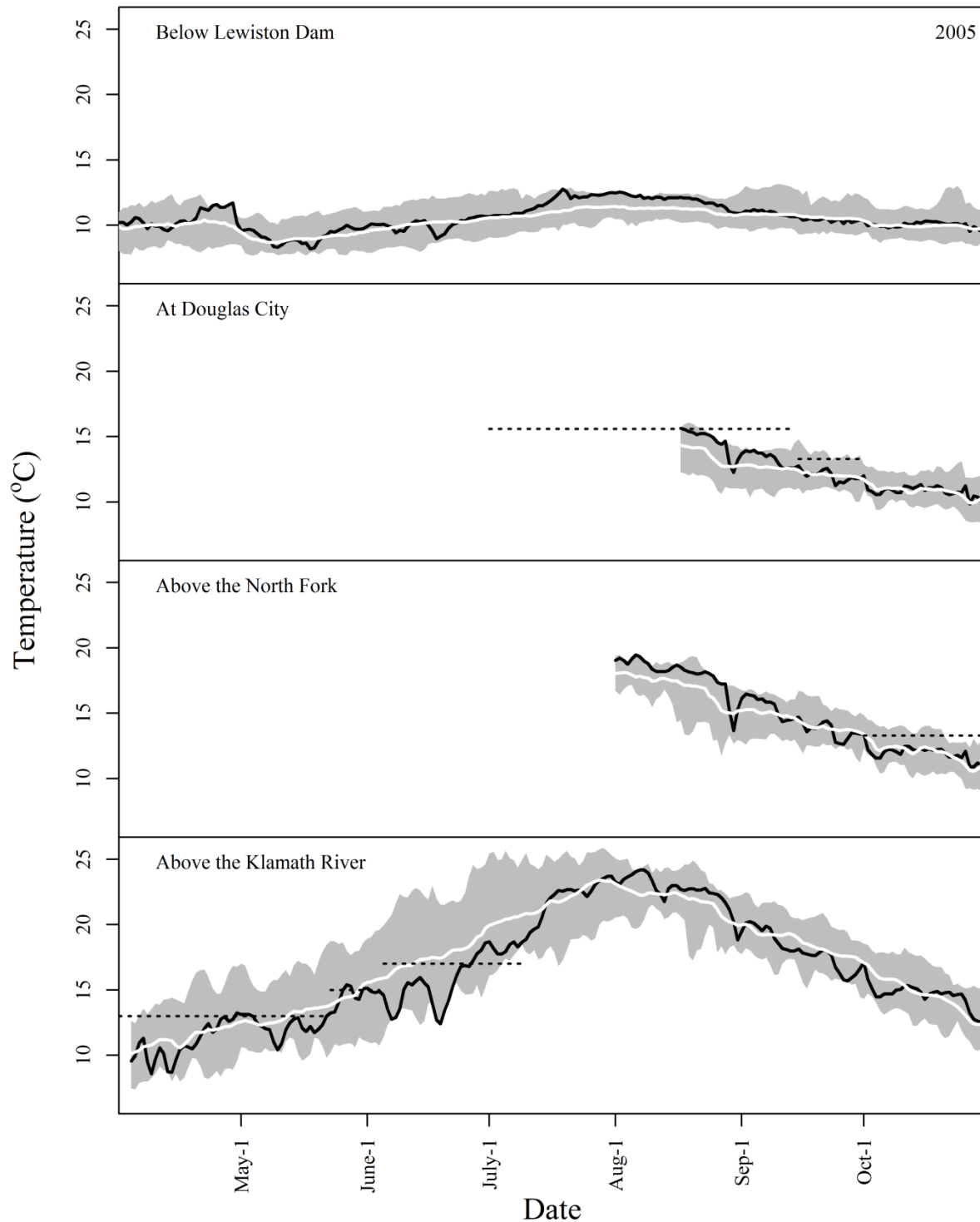
Appendix B3. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2002, with historical conditions. Black line = mean daily water temperatures in 2002; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



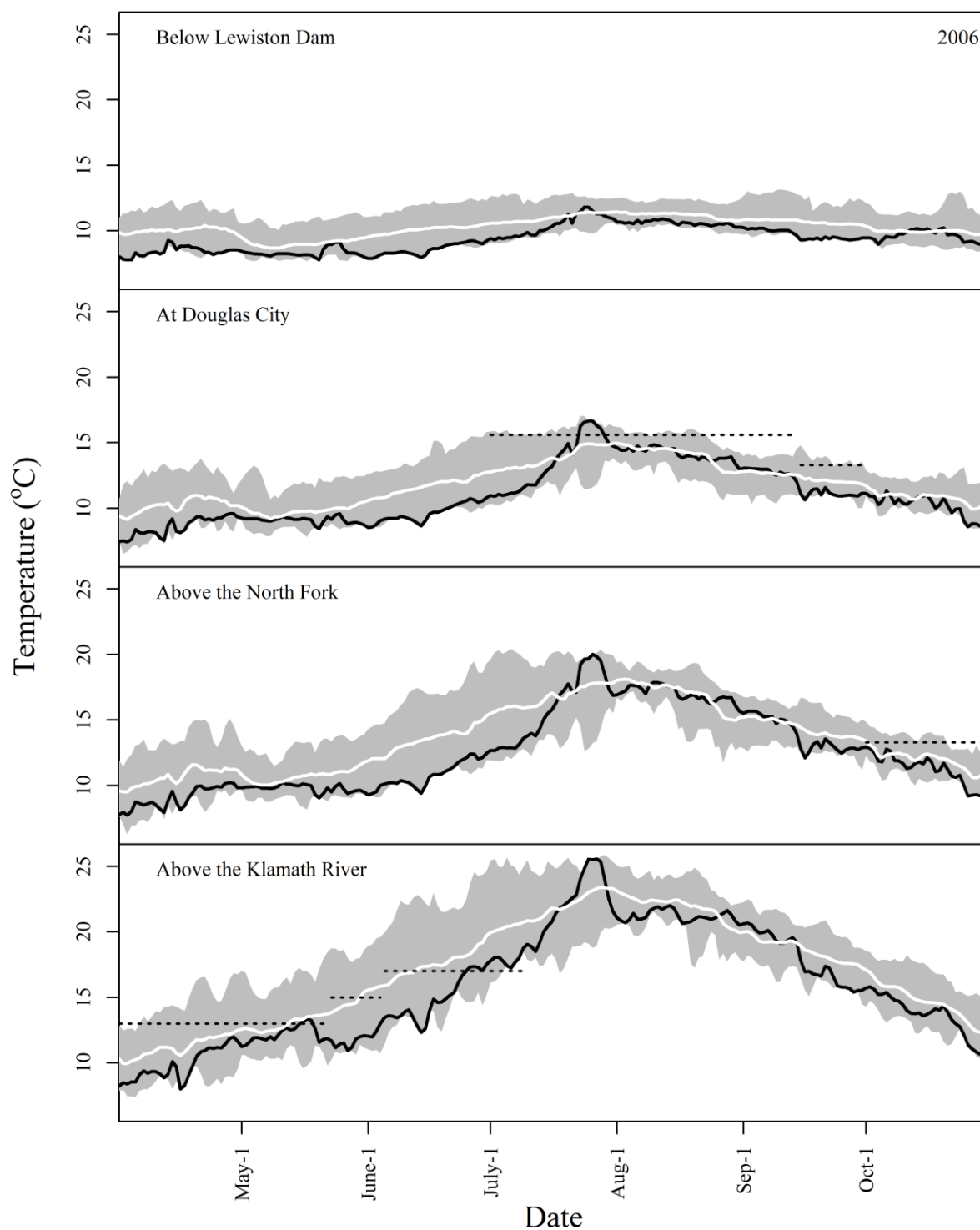
Appendix B4. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2003, with historical conditions. Black line = mean daily water temperatures in 2003; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



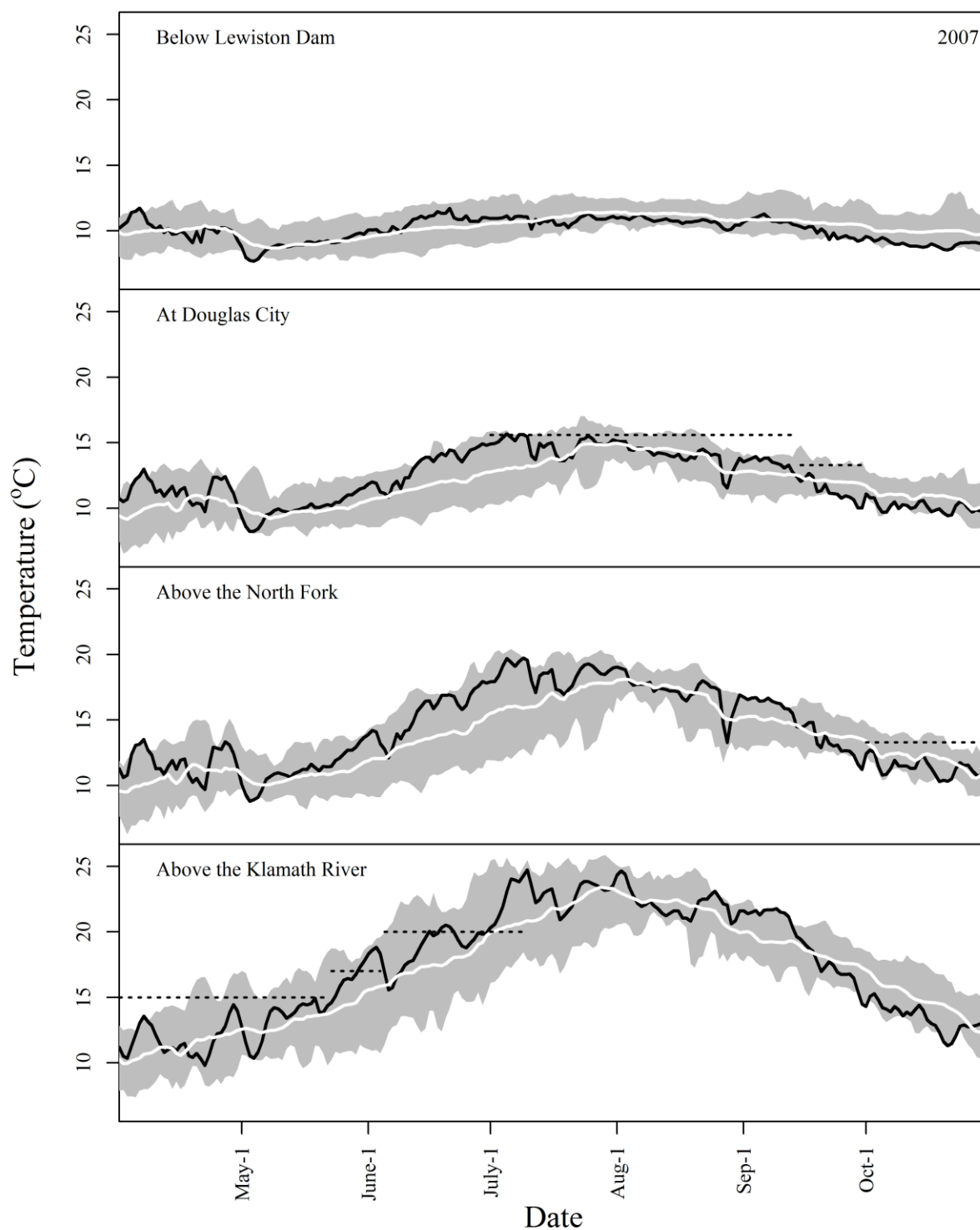
Appendix B5. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2004, with historical conditions. Black line = mean daily water temperatures in 2004; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



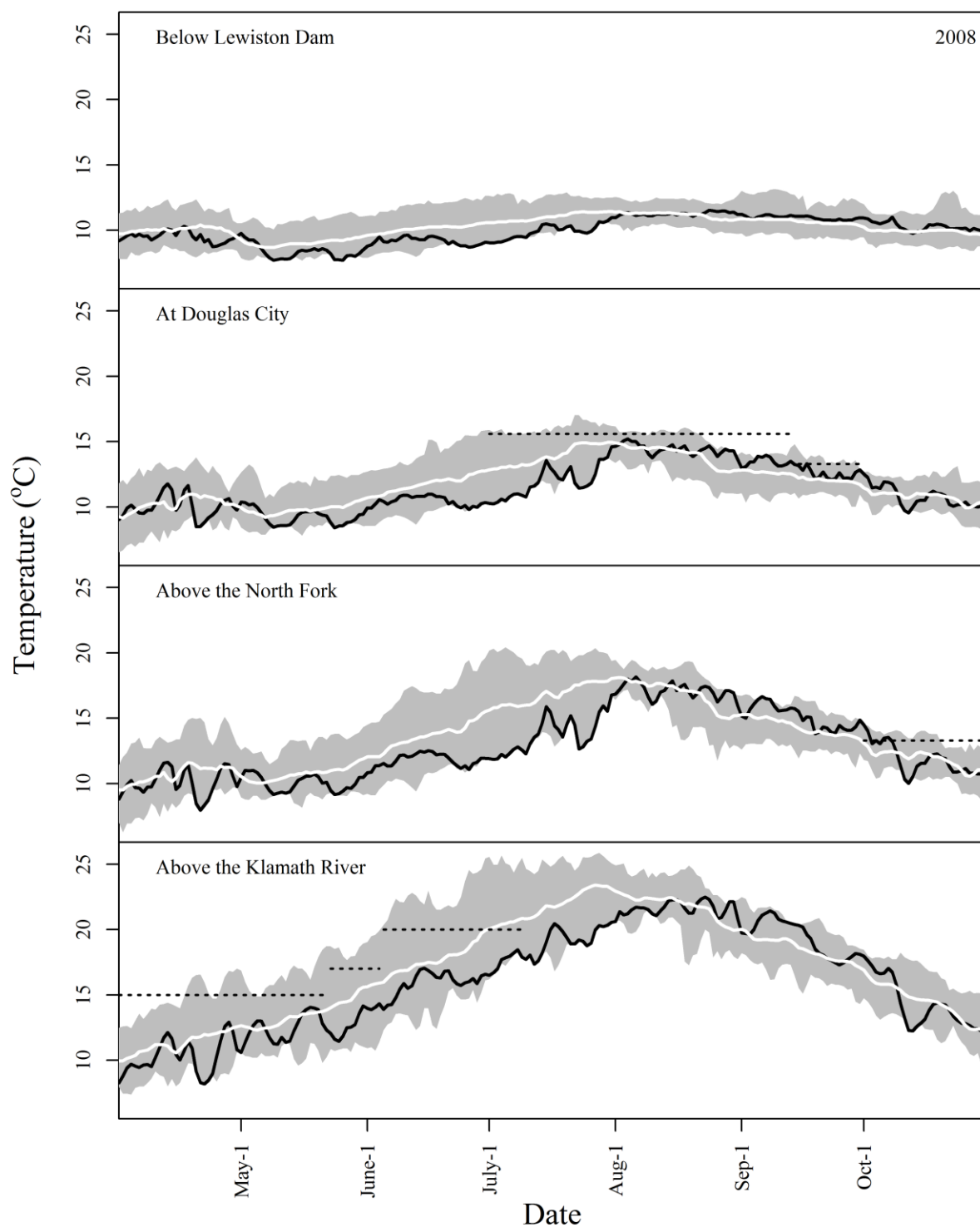
Appendix B6. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2005, with historical conditions. Black line = mean daily water temperatures in 2005; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



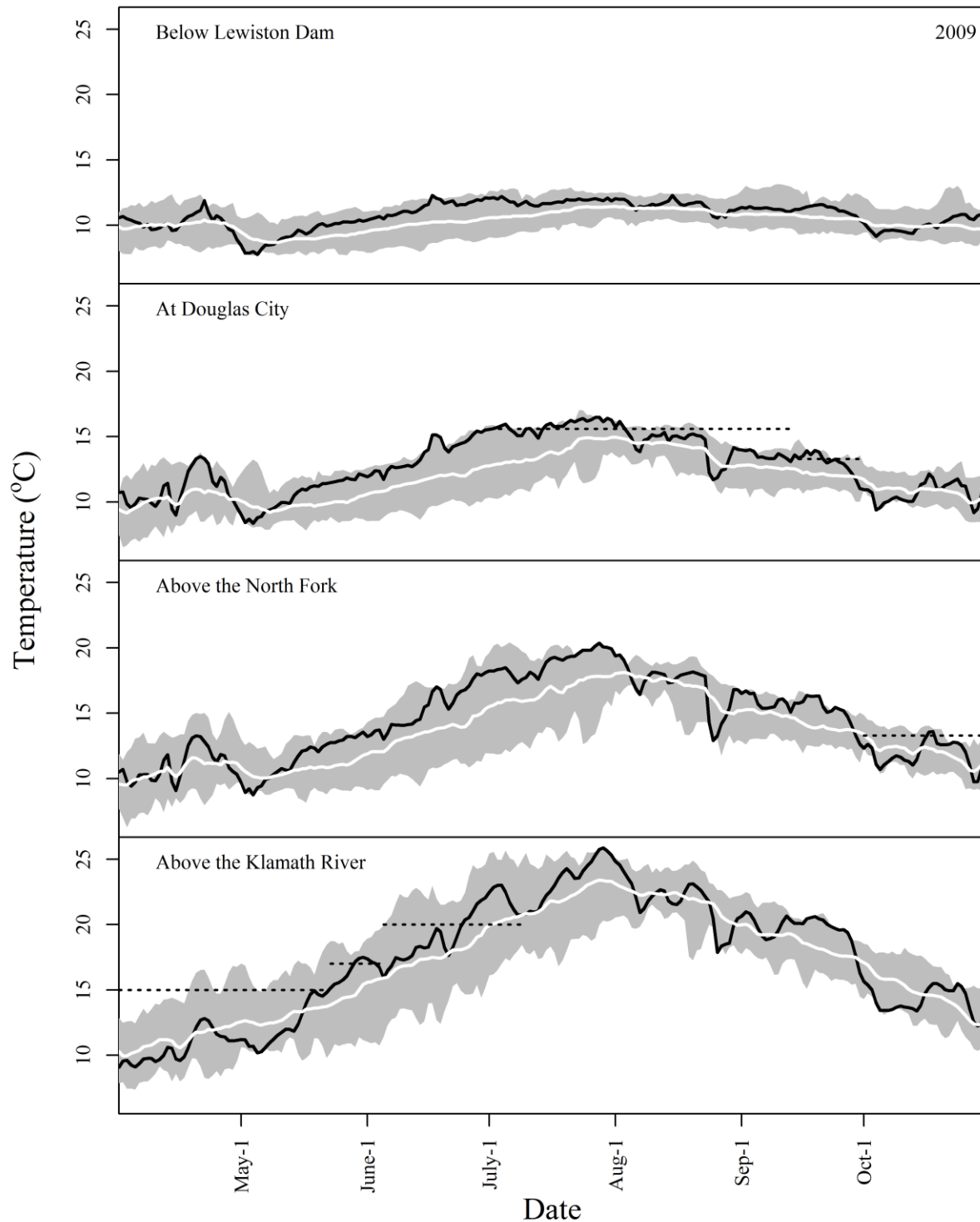
Appendix B7. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2006, with historical conditions. Black line = mean daily water temperatures in 2006; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



Appendix B8. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2007, with historical conditions. Black line = mean daily water temperatures in 2007; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

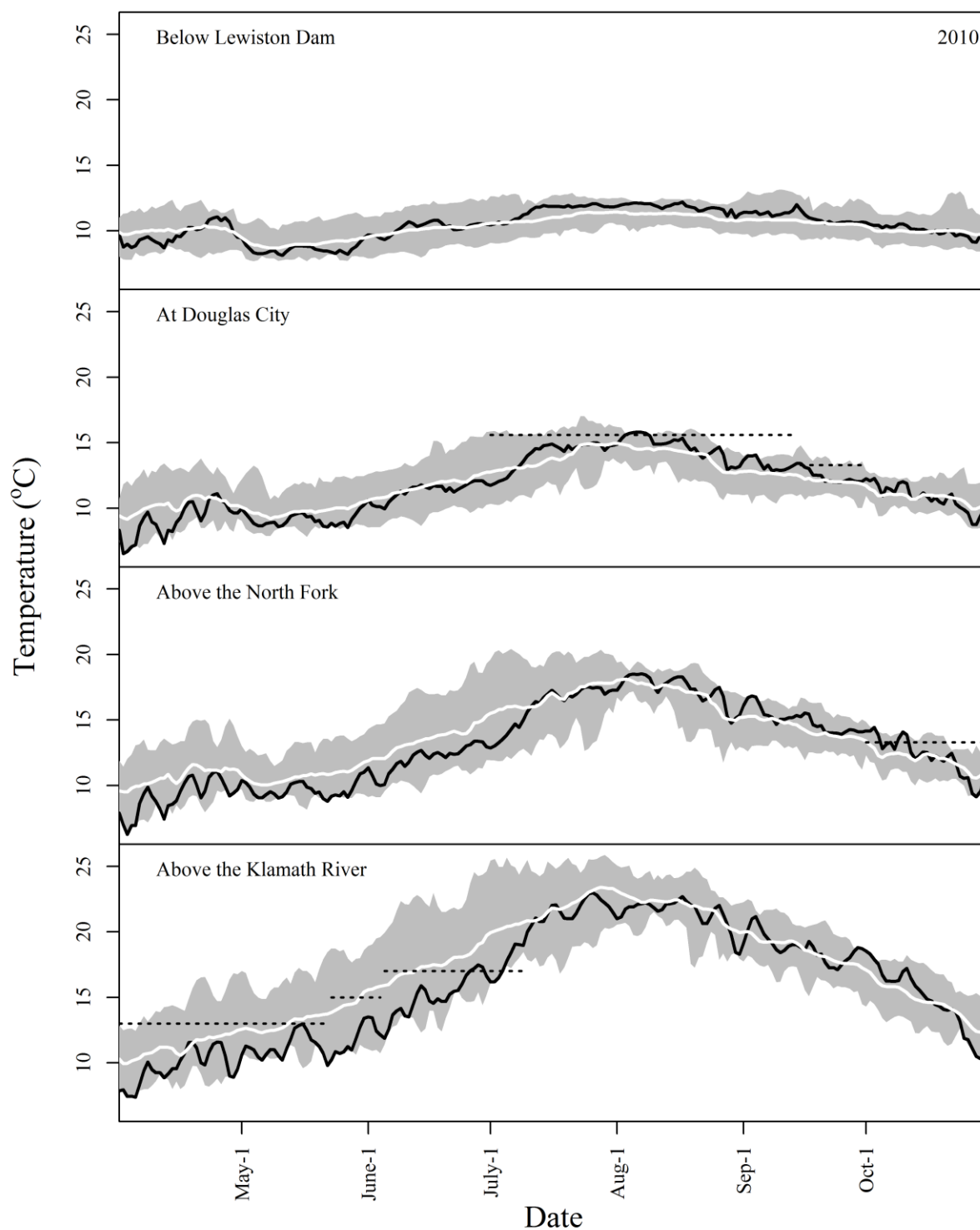


Appendix B9. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2008, with historical conditions. Black line = mean daily water temperatures in 2008; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

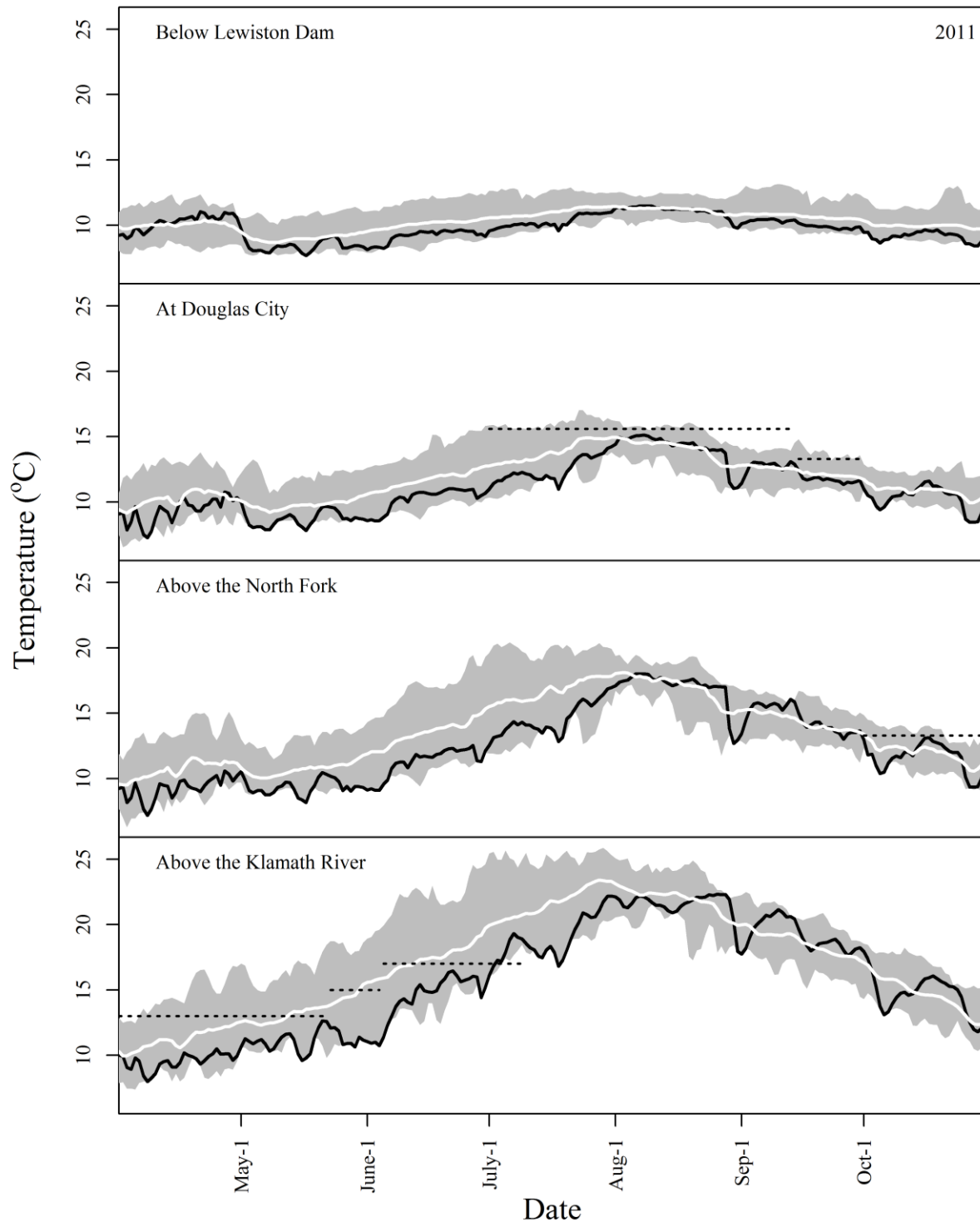


Appendix B10. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2009, with historical conditions. Black line = mean daily water temperatures in 2009; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

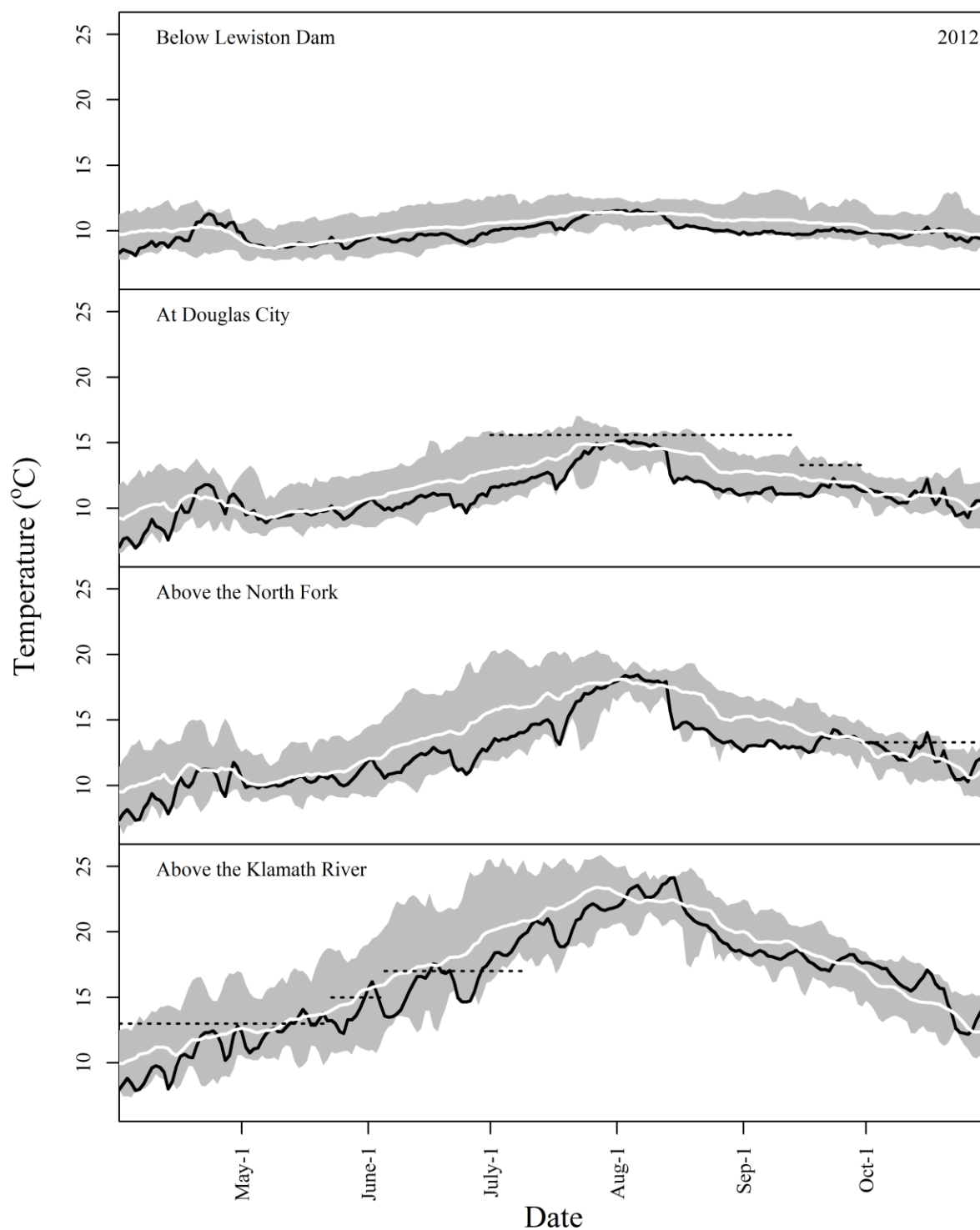




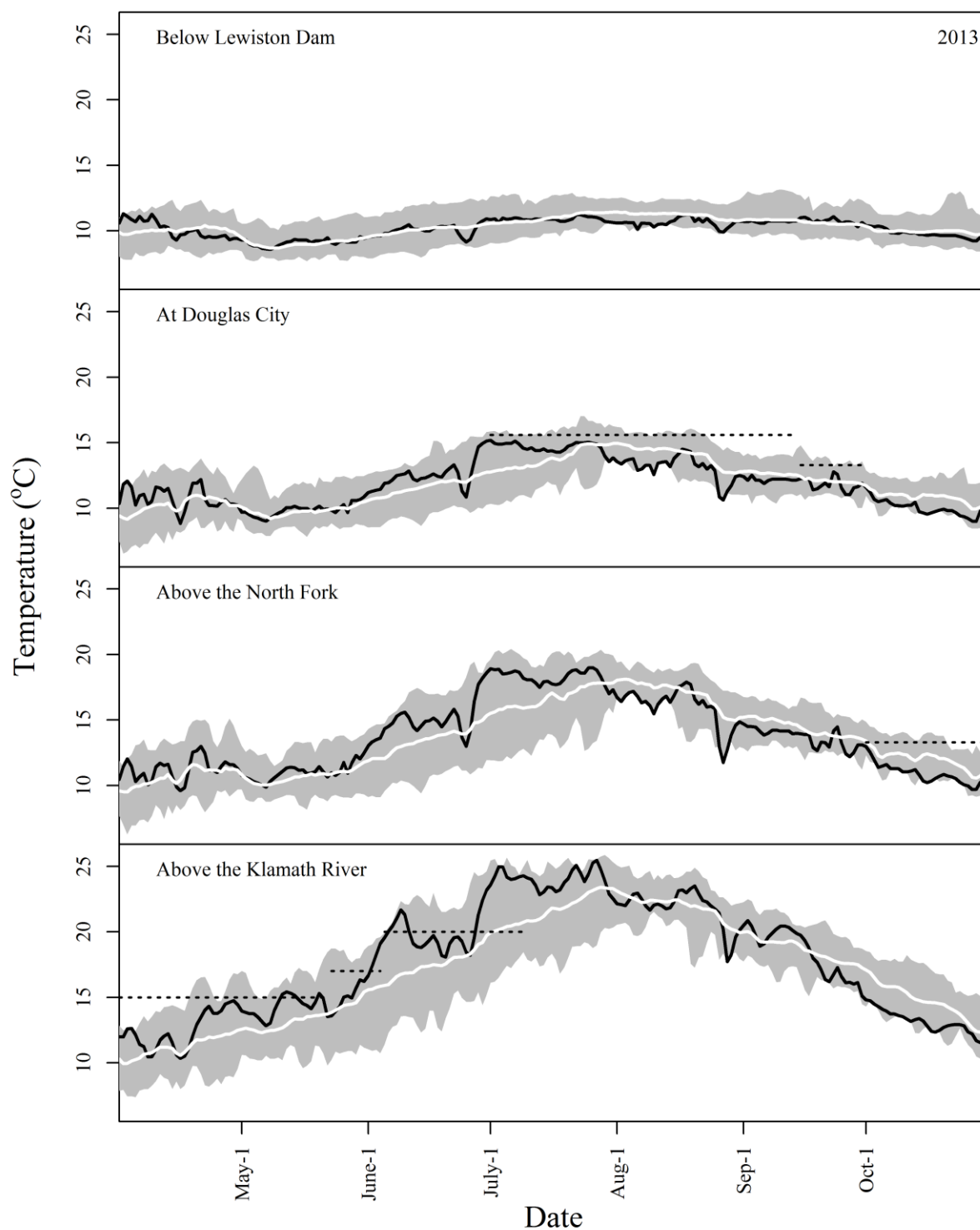
Appendix B11. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2010, with historical conditions. Black line = mean daily water temperatures in 2010; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



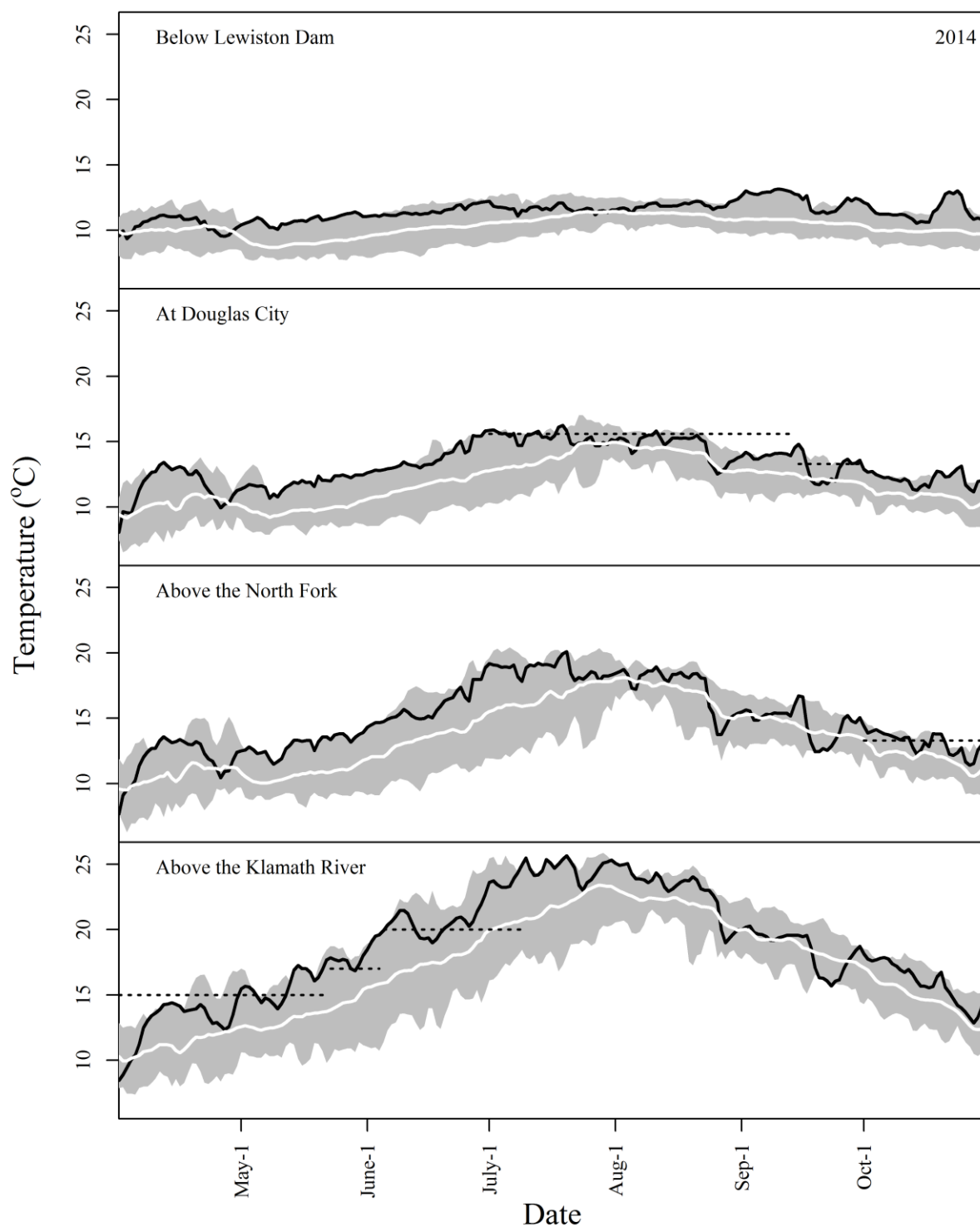
Appendix B12. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2011, with historical conditions. Black line = mean daily water temperatures in 2011; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



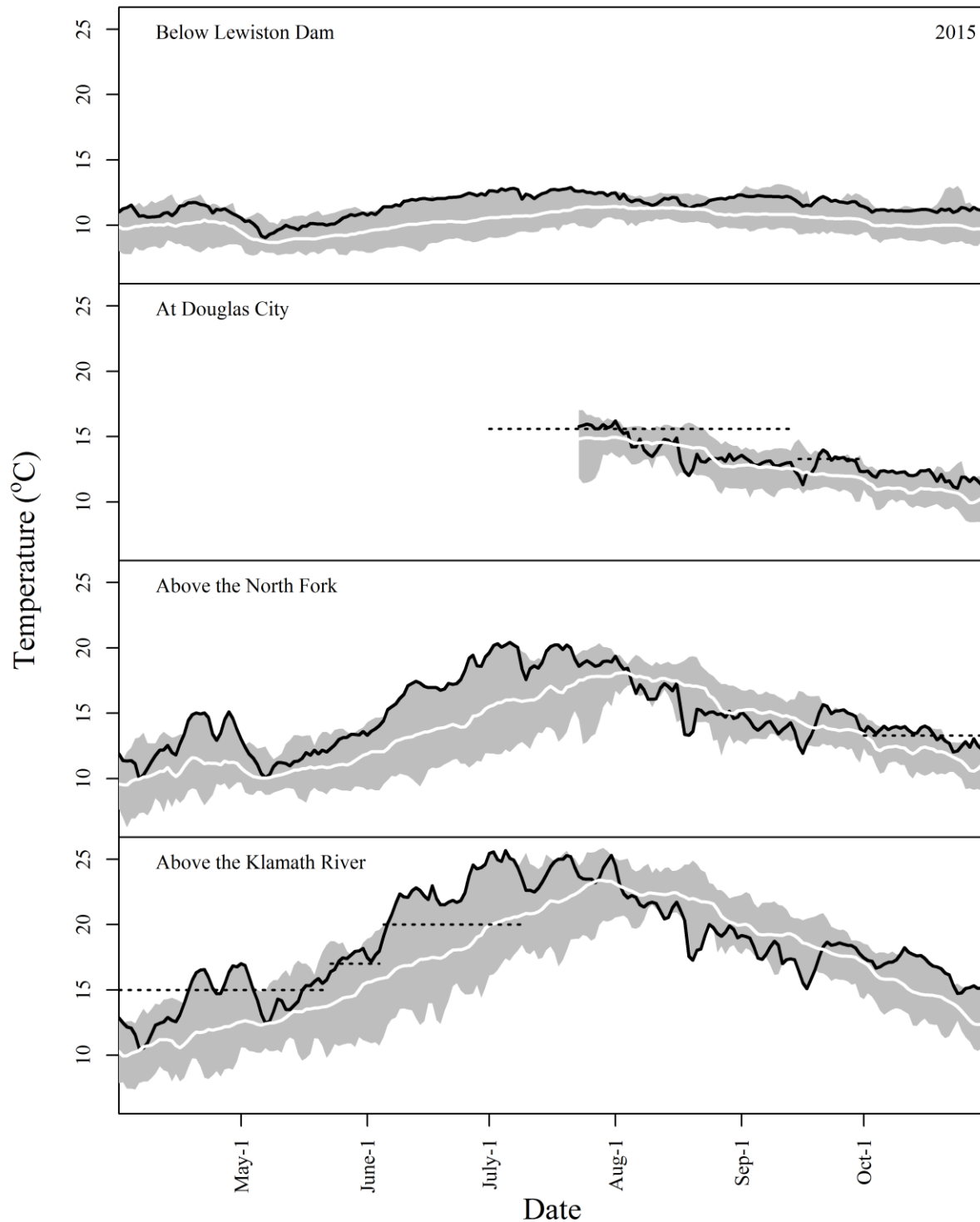
Appendix B13. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2012, with historical conditions. Black line = mean daily water temperatures in 2012; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



Appendix B14. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2013, with historical conditions. Black line = mean daily water temperatures in 2013; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



Appendix B15. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2014, with historical conditions. Black line = mean daily water temperatures in 2014; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



Appendix B16. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2015, with historical conditions. Black line = mean daily water temperatures in 2015; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

Appendix C. The number of days exceeding seven-day average daily maximum (7DADM) EPA criteria for Pacific Northwest water temperatures to protect Pacific salmon at five Klamath River focal locations, April 1 – October 31, 2000-2016. KRIG = Klamath below Iron Gate Dam; KRSC1 = Klamath above the Scott River; KRHC1 = Klamath below Happy Camp; KRWE1 = Klamath above the Trinity River; KRTG2 = Klamath above the mouth.

Year	20°C 7DADM criterion					16°C 7DADM criterion					13°C 7DADM criterion				
	KRIG1	KRSC1	KRHC1	KRWE1	KRTG2	KRIG1	KRSC1	KRHC1	KRWE1	KRTG2	KRIG1	KRSC1	KRHC1	KRWE1	KRTG2
2000	74	--	98 <sup>d</sup>	--	--	141	--	--	--	--	28	--	--	--	--
2001	81	--	126 <sup>e</sup>	119 <sup>f</sup>	--	158	--	--	162 <sup>f</sup>	--	31	--	--	--	--
2002	78 <sup>a</sup>	--	--	95 <sup>g</sup>	--	--	--	--	139 <sup>g</sup>	--	--	--	--	--	--
2003	102	102	97	86	83	142	142	136	133	141	31	31	31	31	31
2004	85 <sup>b</sup>	94	94	91	84	156 <sup>b</sup>	154	146	140	138	--	37	28	26	30
2005	75 <sup>c</sup>	83	81	75	74	--	135	128	120	129	--	36	30	31	32
2006	89	90	89	87	83	154	151	130	127	124	31	30	27	27	29
2007	95	106	105	--	95	147	147	146	--	136	26	25	25	--	27
2008	81	87	86	83	74	146	135	122	121	123	30	29	27	29	31
2009	86	120	109	102	99	144	142	139	137	143	35	37	35	33	38
2010	74	84	73	63	64	130	128	118	115	118	31	28	26	26	28
2011	83	84	77	64	64	129	128	116	110	121	31	30	29	30	31
2012	85	92	88	80	67	163	158	142	138	138	32	37	26	26	31
2013	95	110	109	104	99	151	152	147	140	138	33	34	33	34	37
2014	98	118	128	117	110	158	167	168	161	162	48	52	51	44	51
2015	95	112	115	112	101	161	175	176	176	171	40	45	45	43	47
2016	91	104	103	99	86	156	155	149	149	141	49	50	26	23	33

<sup>a</sup> Data unavailable prior to 5/14 for KRIG1 in 2002. We assumed 7DADM temperatures did not reach or exceed 20.0 C before this date.

<sup>b</sup> Data unavailable prior to 4/20 for KRIG1 in 2004. We assumed 7DADM temperatures did not reach or exceed 16.0 C before this date.

<sup>c</sup> Data unavailable prior to 6/1 for KRIG1 in 2005. We assumed 7DADM temperatures did not reach or exceed 20.0 C before this date.

<sup>d</sup> Data unavailable prior to 6/10 and after 10/3 for KRHC1 in 2000. We assumed 7DADM temperatures did not reach or exceed 20.0 C outside these dates.

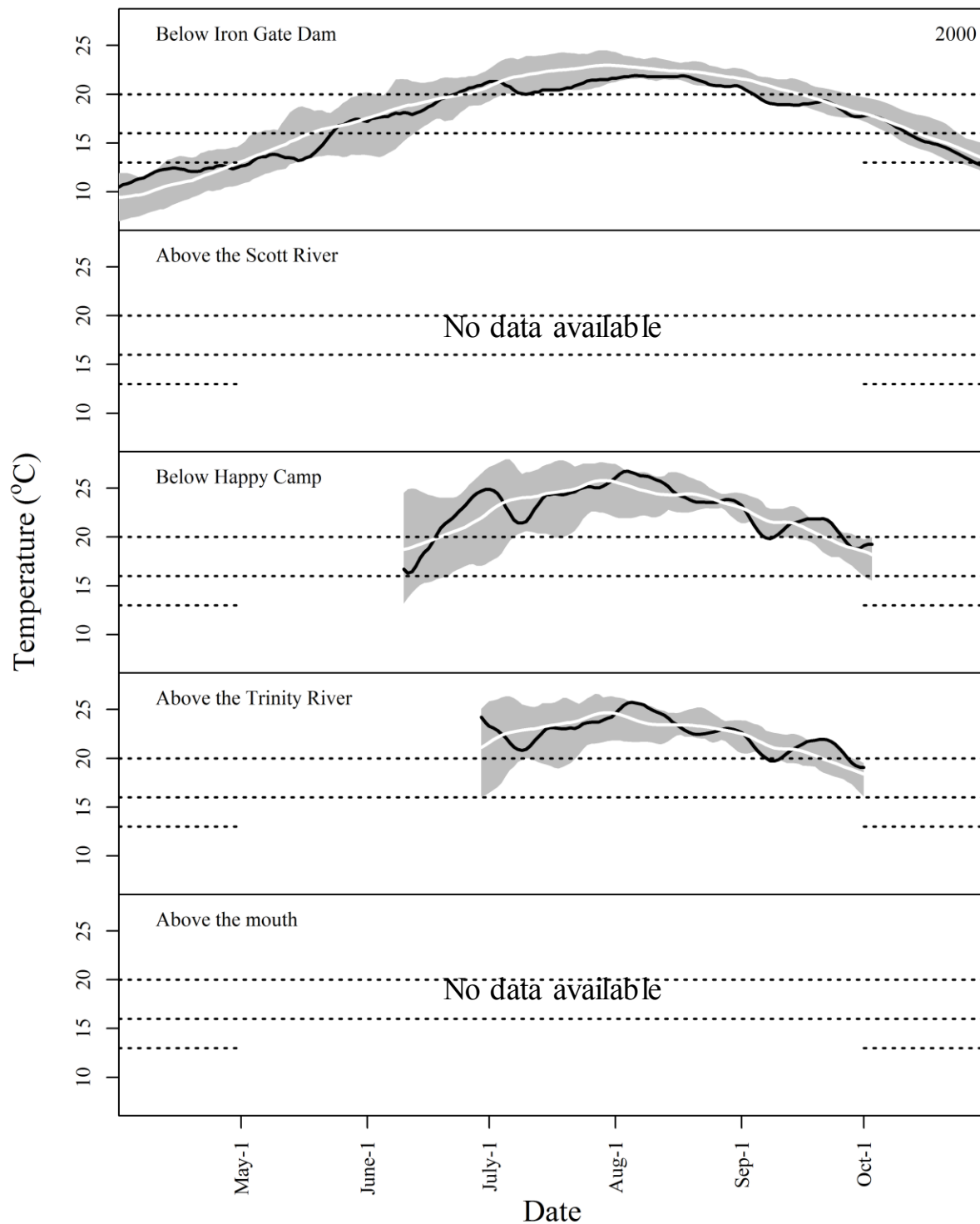
<sup>e</sup> Data unavailable prior to 4/29 and after 10/10 for KRHC1 in 2001. We assumed 7DADM temperatures did not reach or exceed 20.0 C outside these dates.

<sup>f</sup> Data unavailable prior to 5/3 and after 10/22 for KRWE1 in 2001. We assumed 7DADM temperatures did not reach or exceed 16.0 C outside these dates.

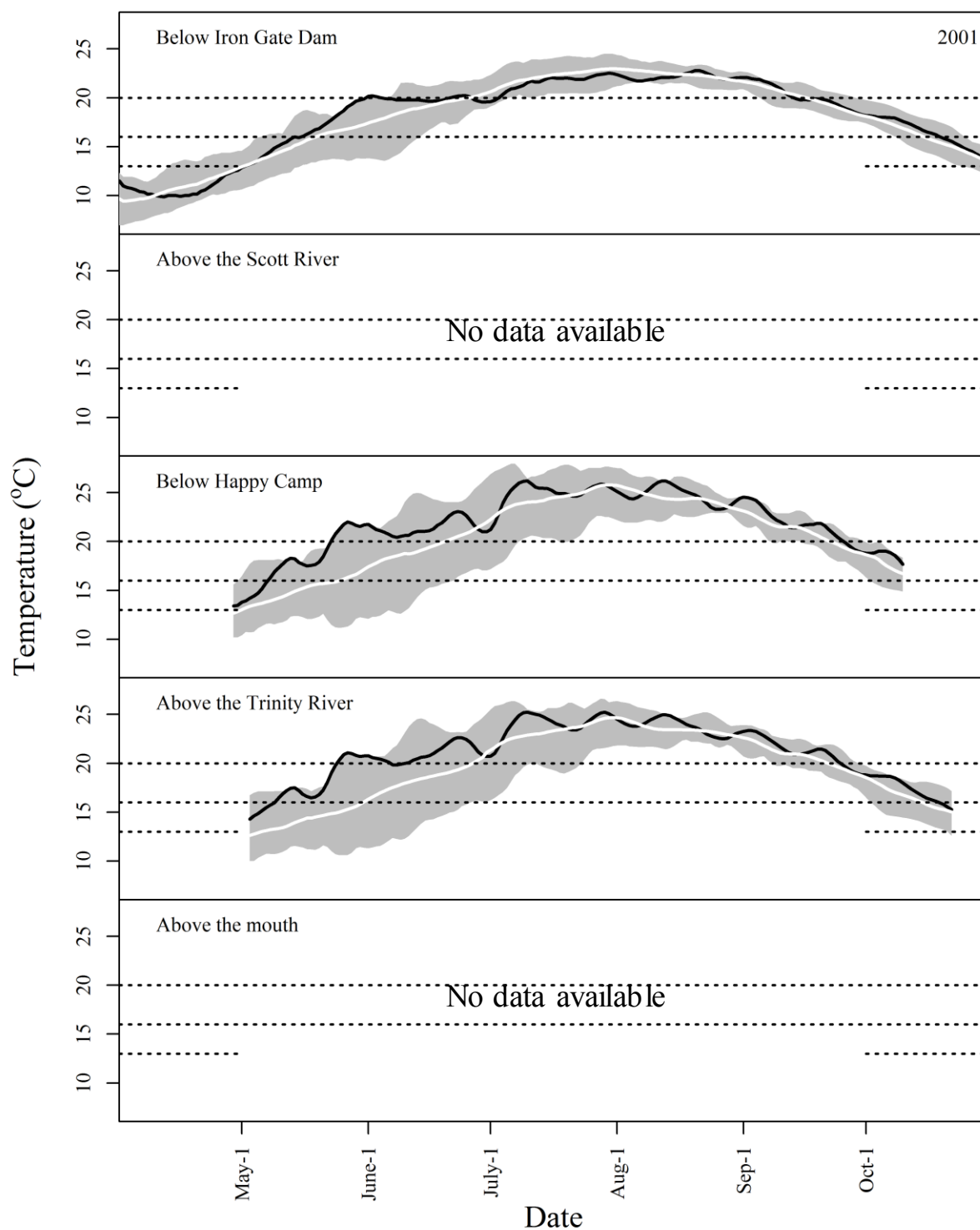
<sup>g</sup> Data unavailable prior to 4/26 for KRWE1 in 2002. We assumed 7DADM temperatures did not reach or exceed 16.0 C before this date.

Appendix D. Seven-day average daily maximum water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2000-2015, with historical conditions. Includes both observed and infilled water temperatures.

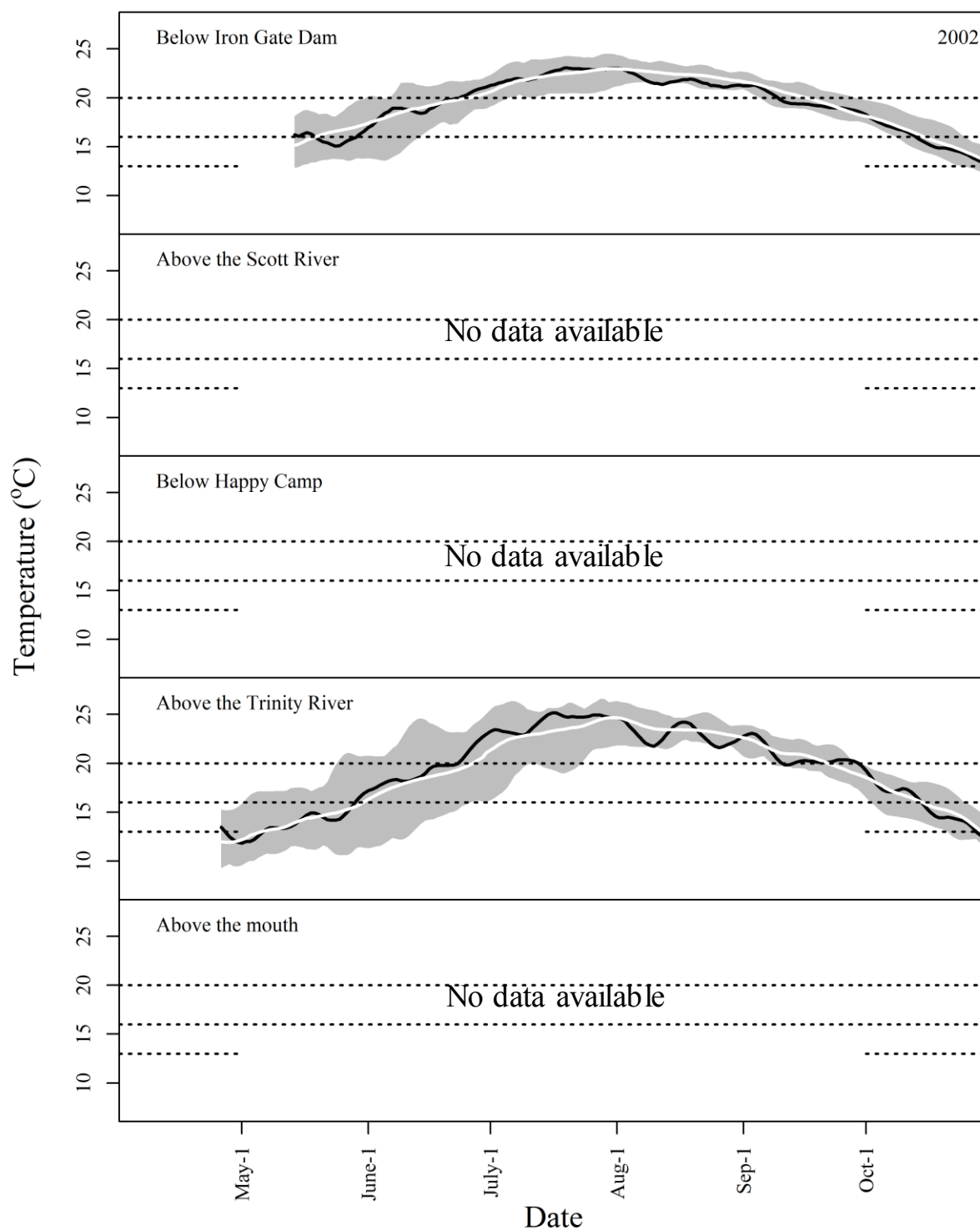




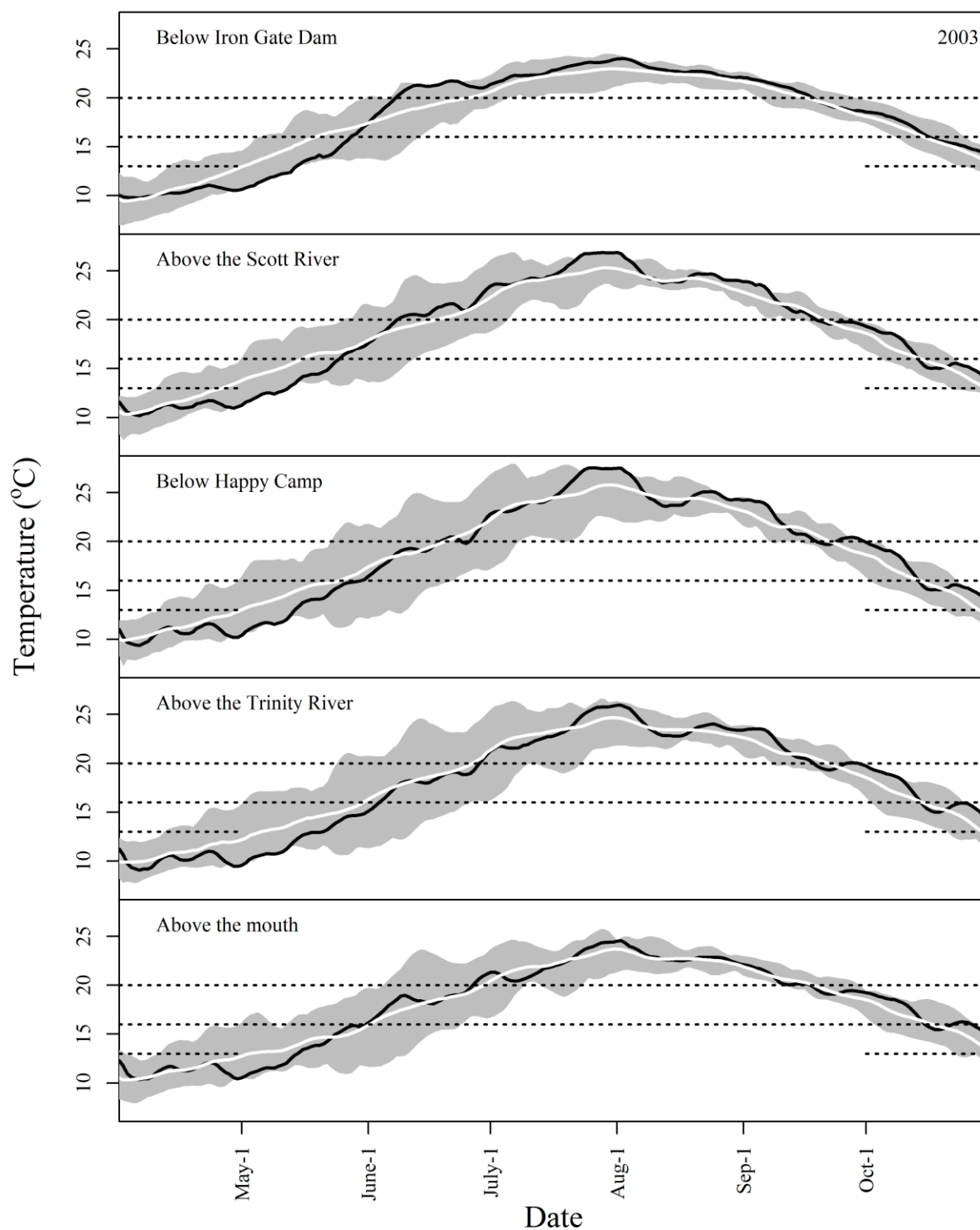
Appendix D1. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2000, with historical conditions. Black line = 7DADM water temperatures in 2000; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



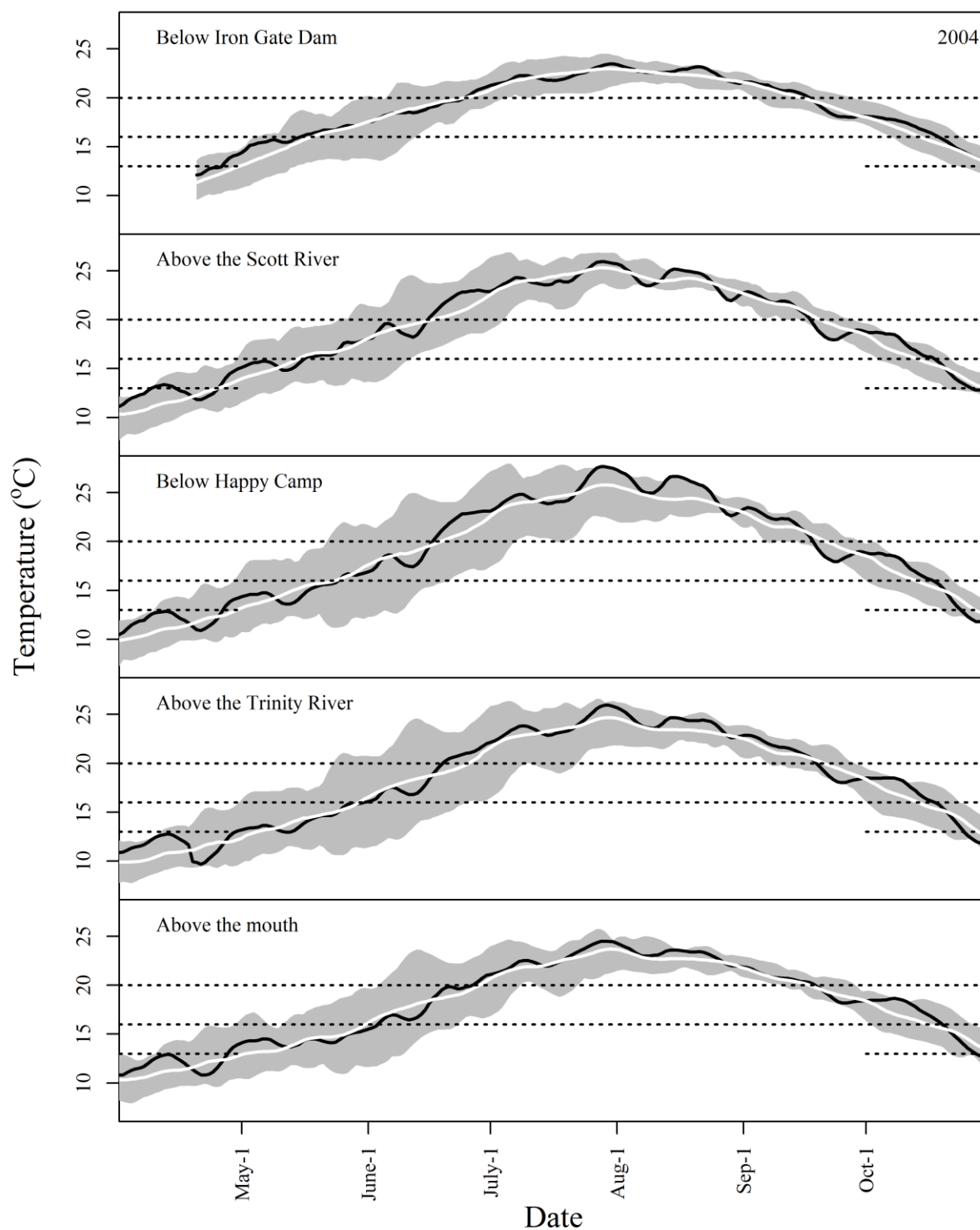
Appendix D2. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2001, with historical conditions. Black line = 7DADM water temperatures in 2001; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



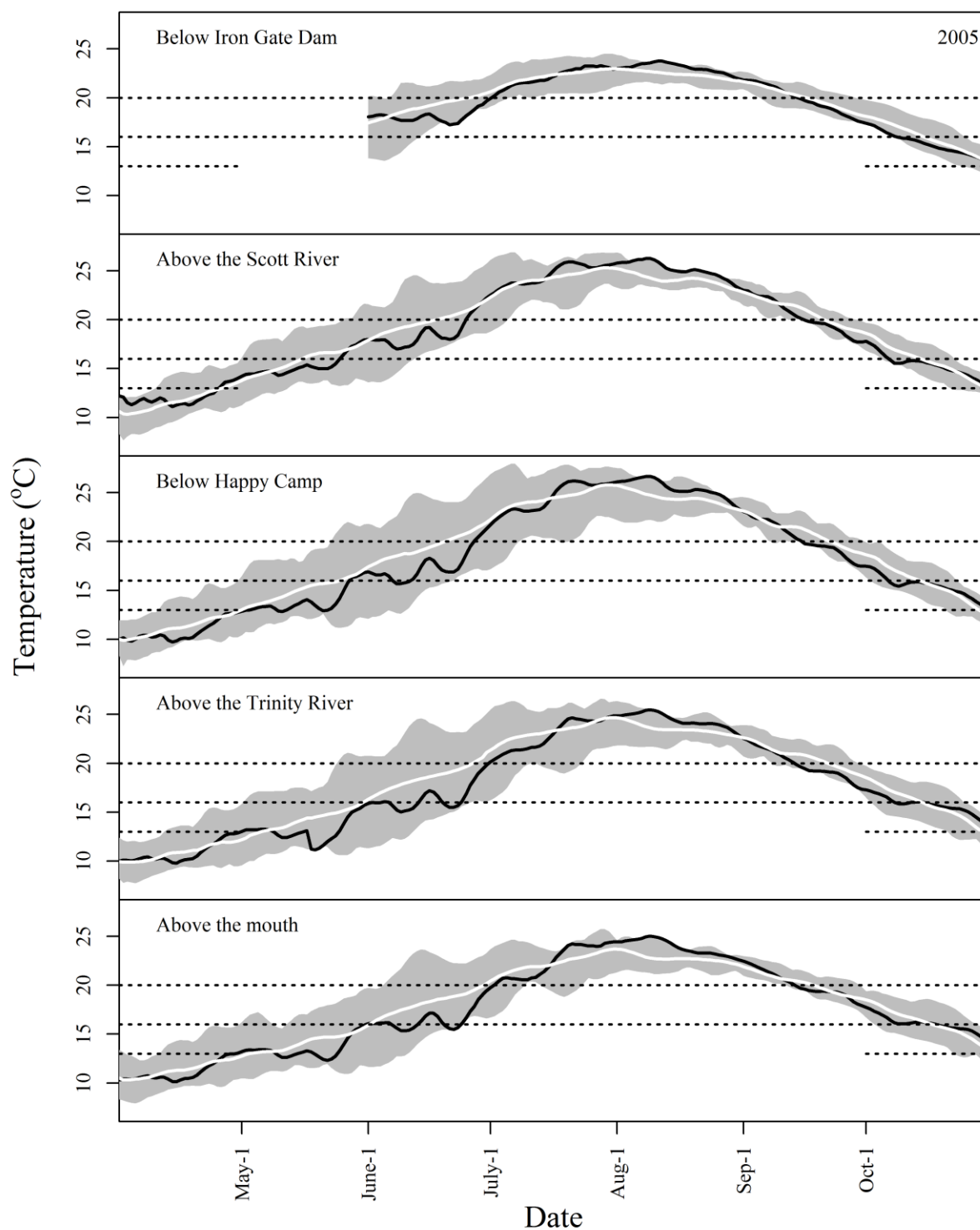
Appendix D3. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2002, with historical conditions. Black line = 7DADM water temperatures in 2002; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



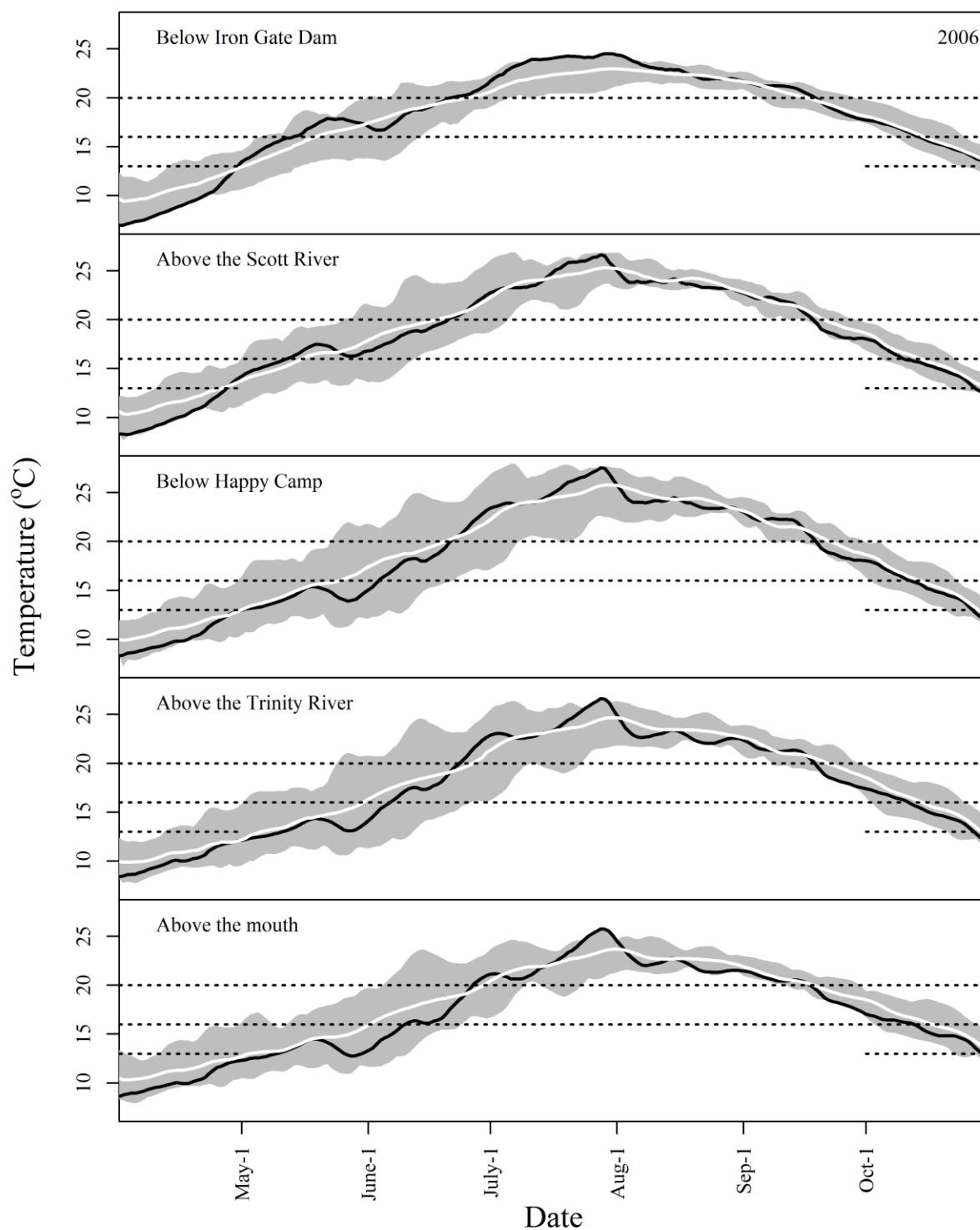
Appendix D4. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2003, with historical conditions. Black line = 7DADM water temperatures in 2003; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



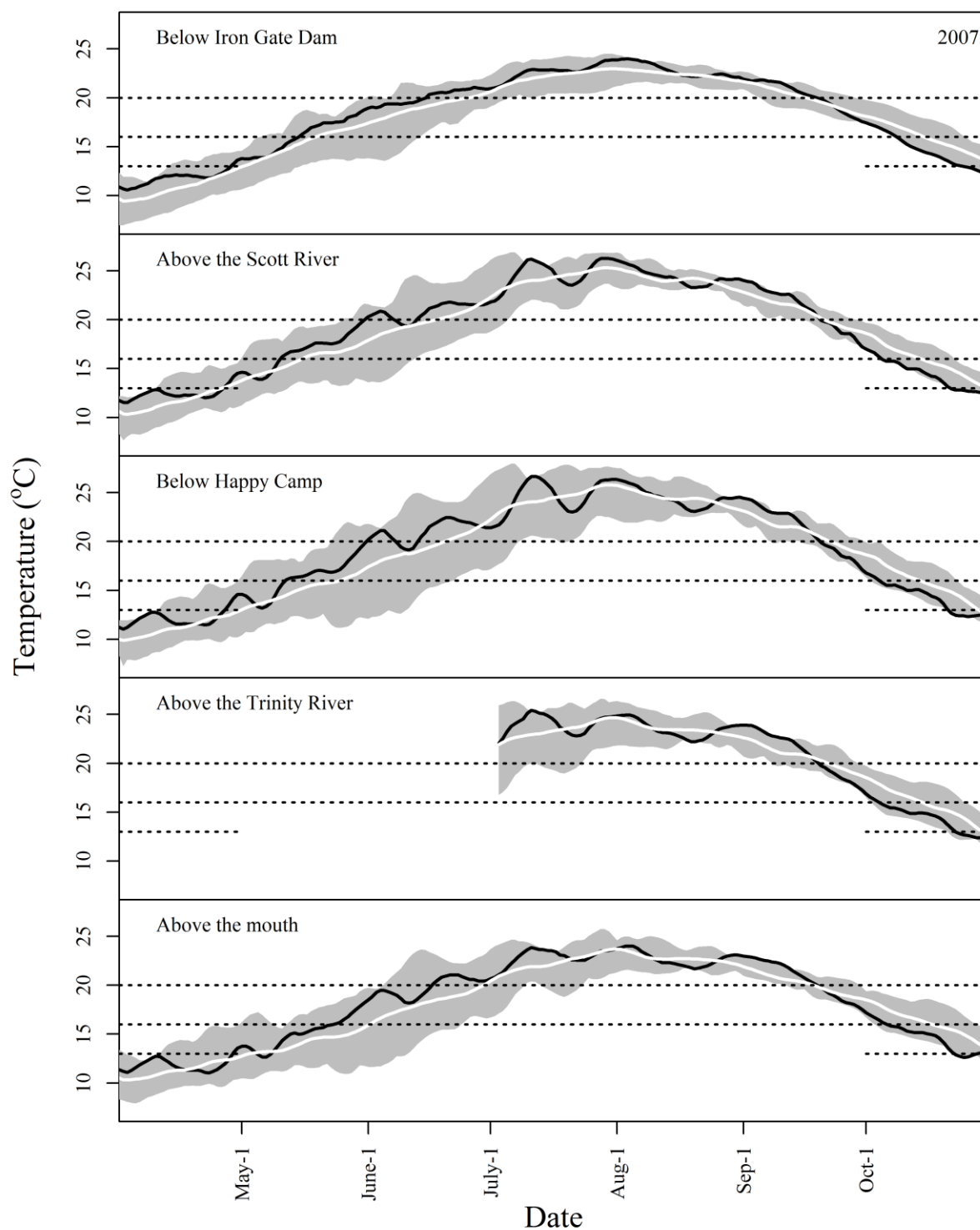
Appendix D5. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2004, with historical conditions. Black line = 7DADM water temperatures in 2004; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



Appendix D6. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2005, with historical conditions. Black line = 7DADM water temperatures in 2005; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

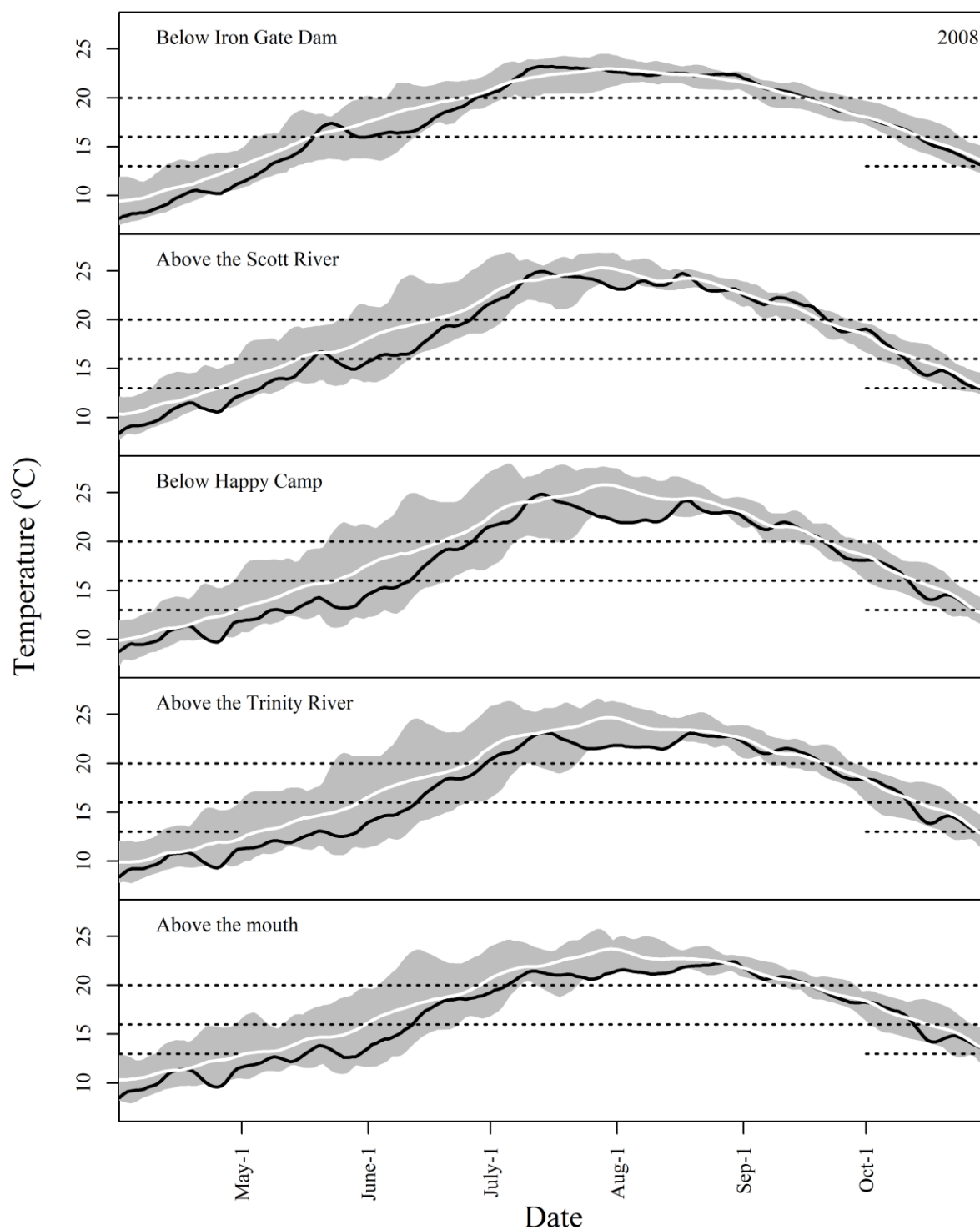


Appendix D7. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2006, with historical conditions. Black line = 7DADM water temperatures in 2006; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

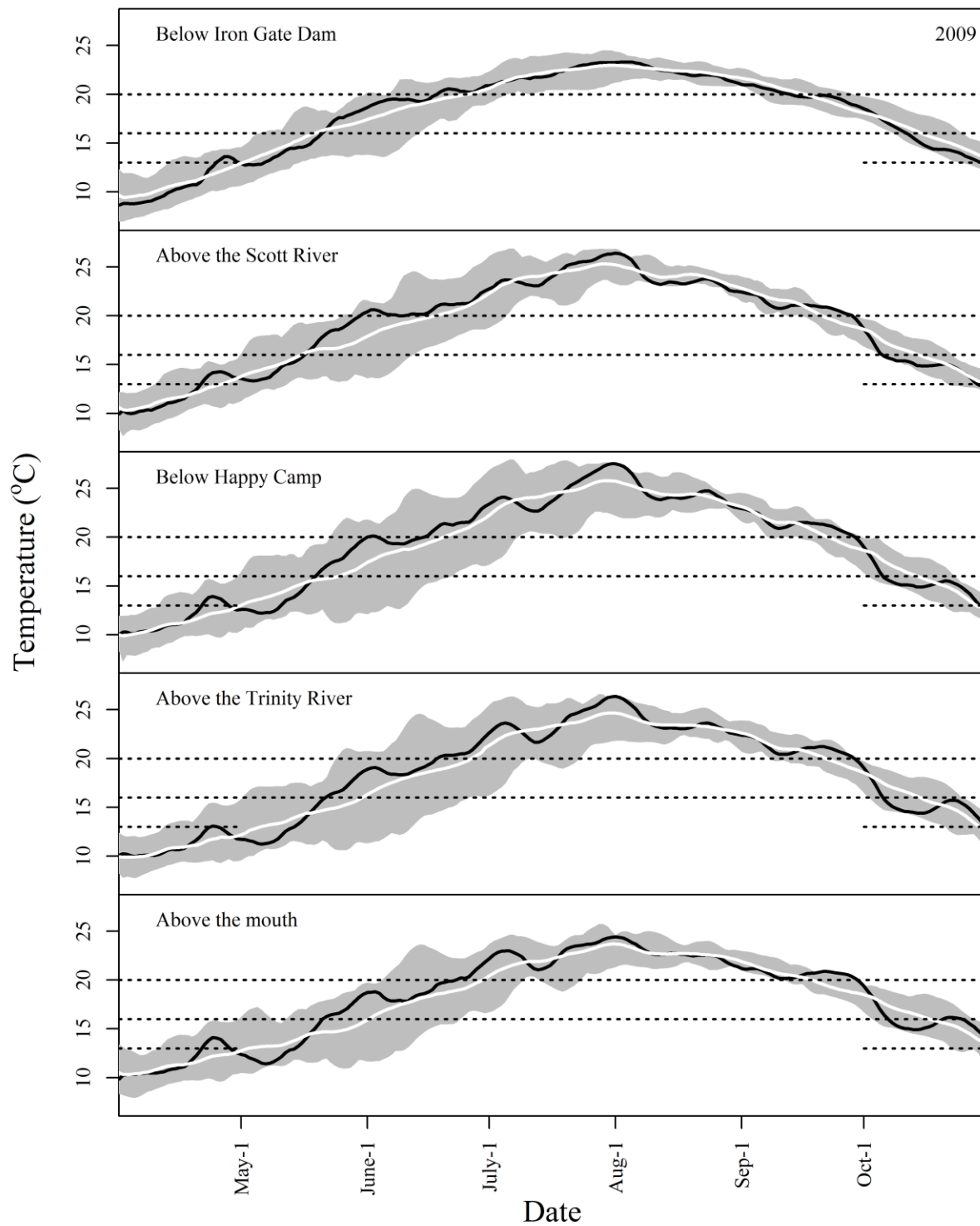


Appendix D8. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2007, with historical conditions. Black line = 7DADM water temperatures in 2007; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

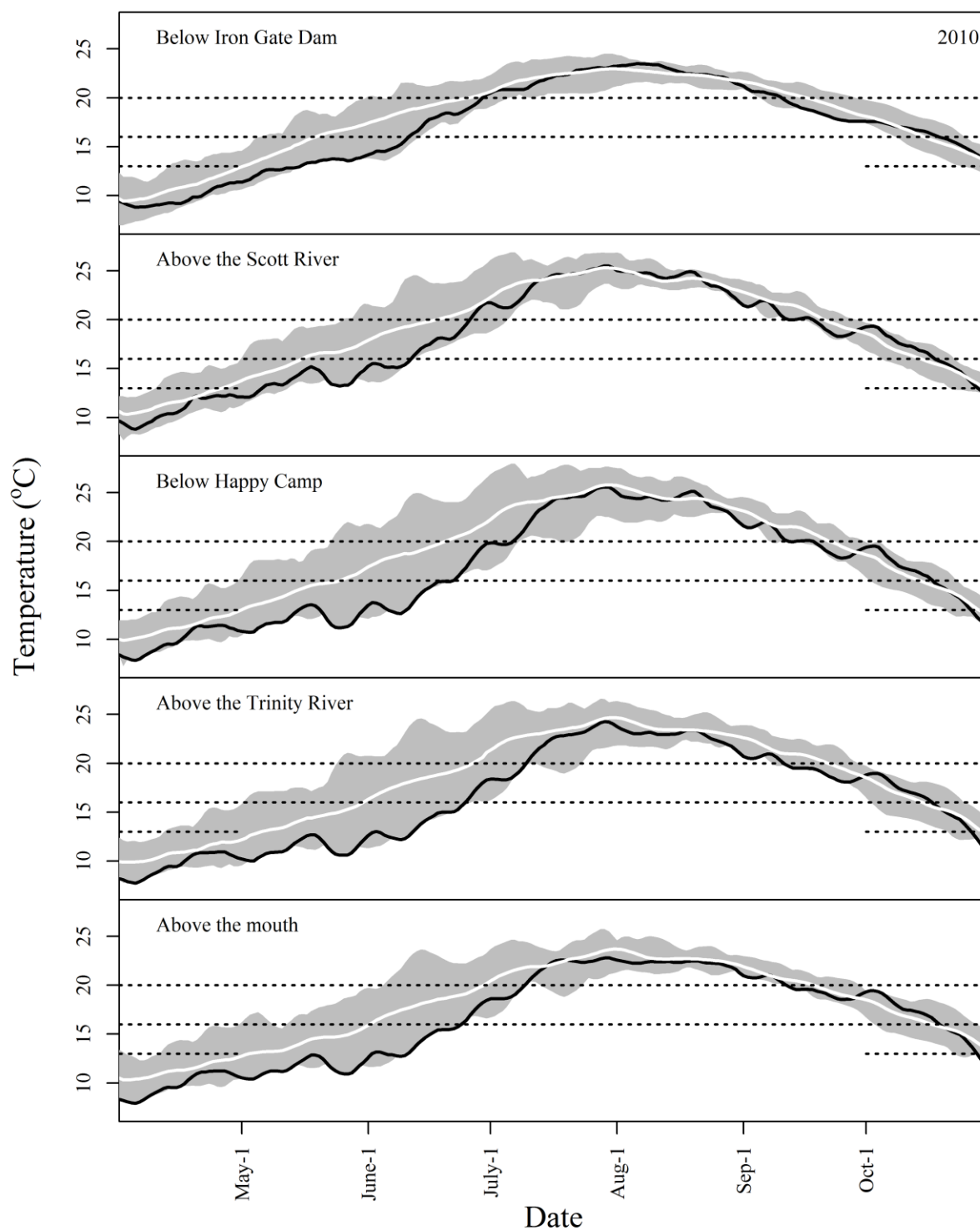




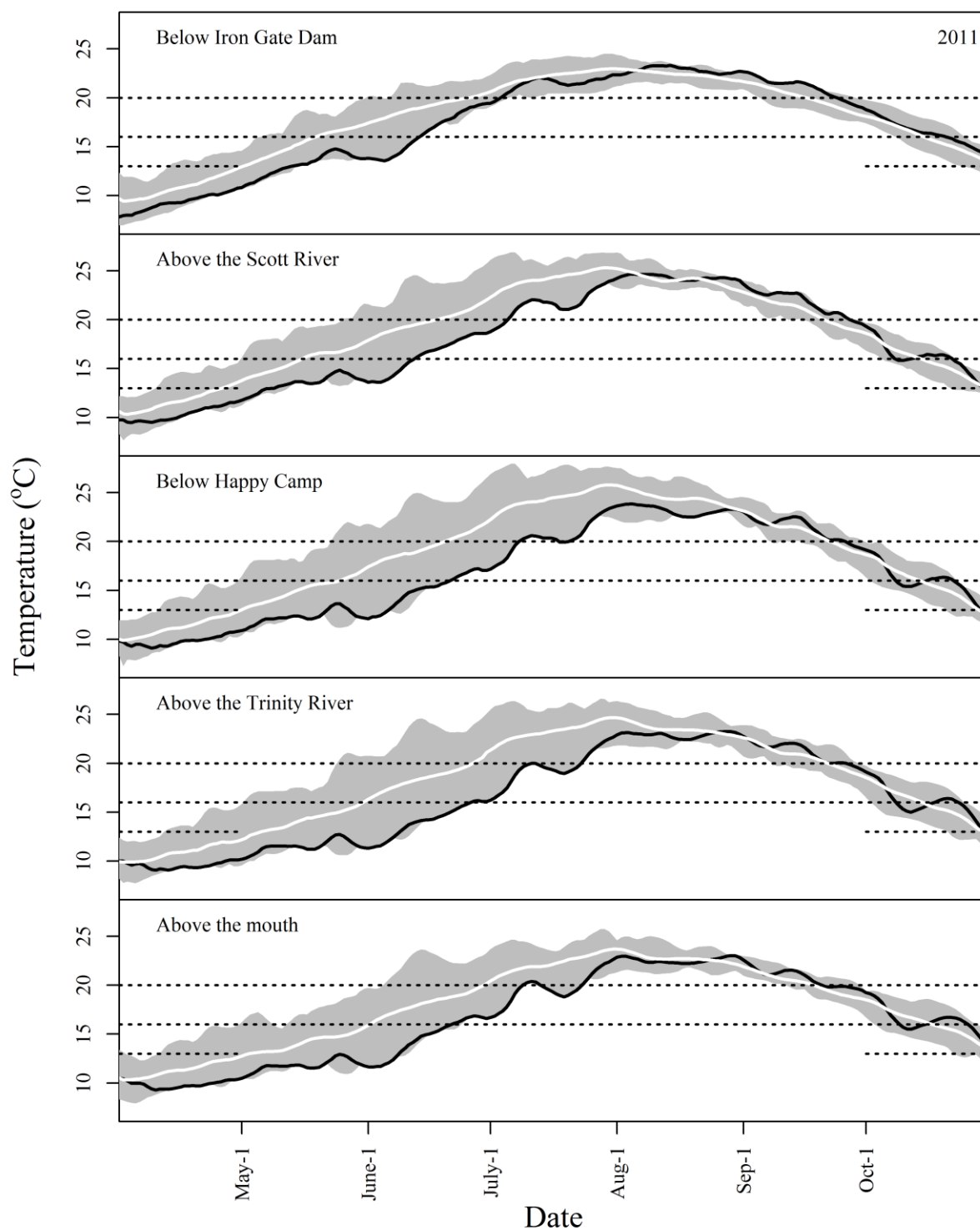
Appendix D9. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2008, with historical conditions. Black line = 7DADM water temperatures in 2008; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



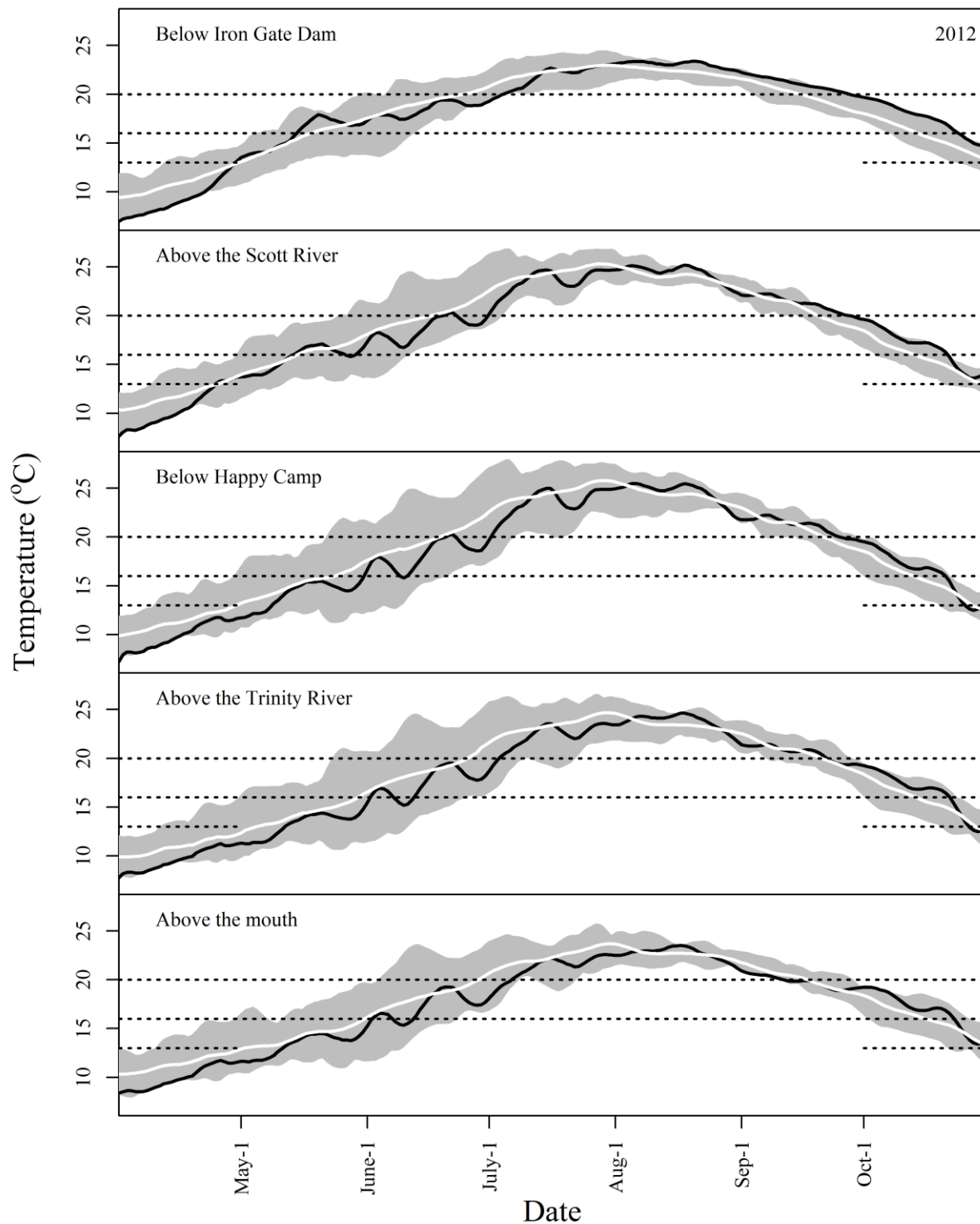
Appendix D10. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2009, with historical conditions. Black line = 7DADM water temperatures in 2009; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



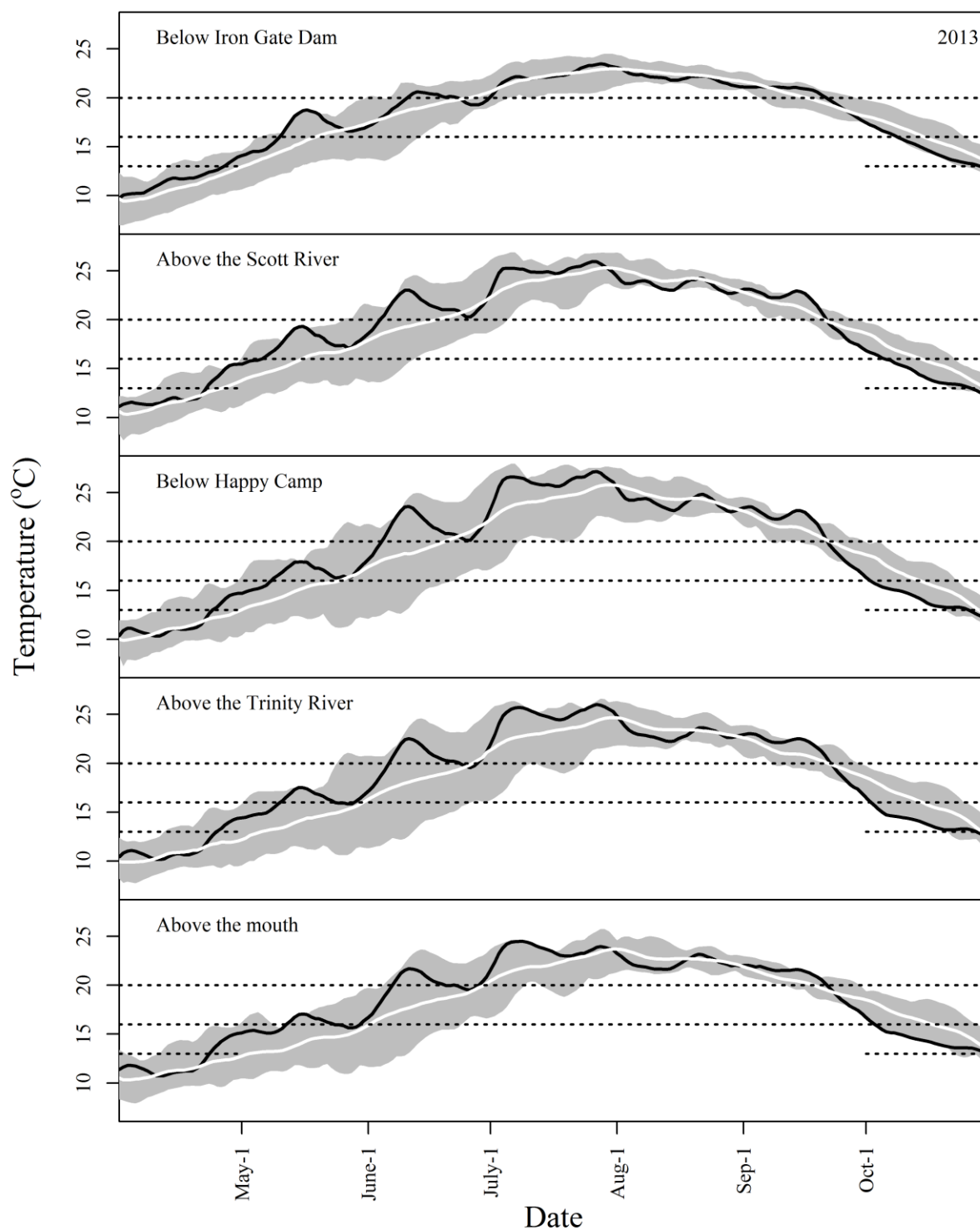
Appendix D11. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2010, with historical conditions. Black line = 7DADM water temperatures in 2010; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



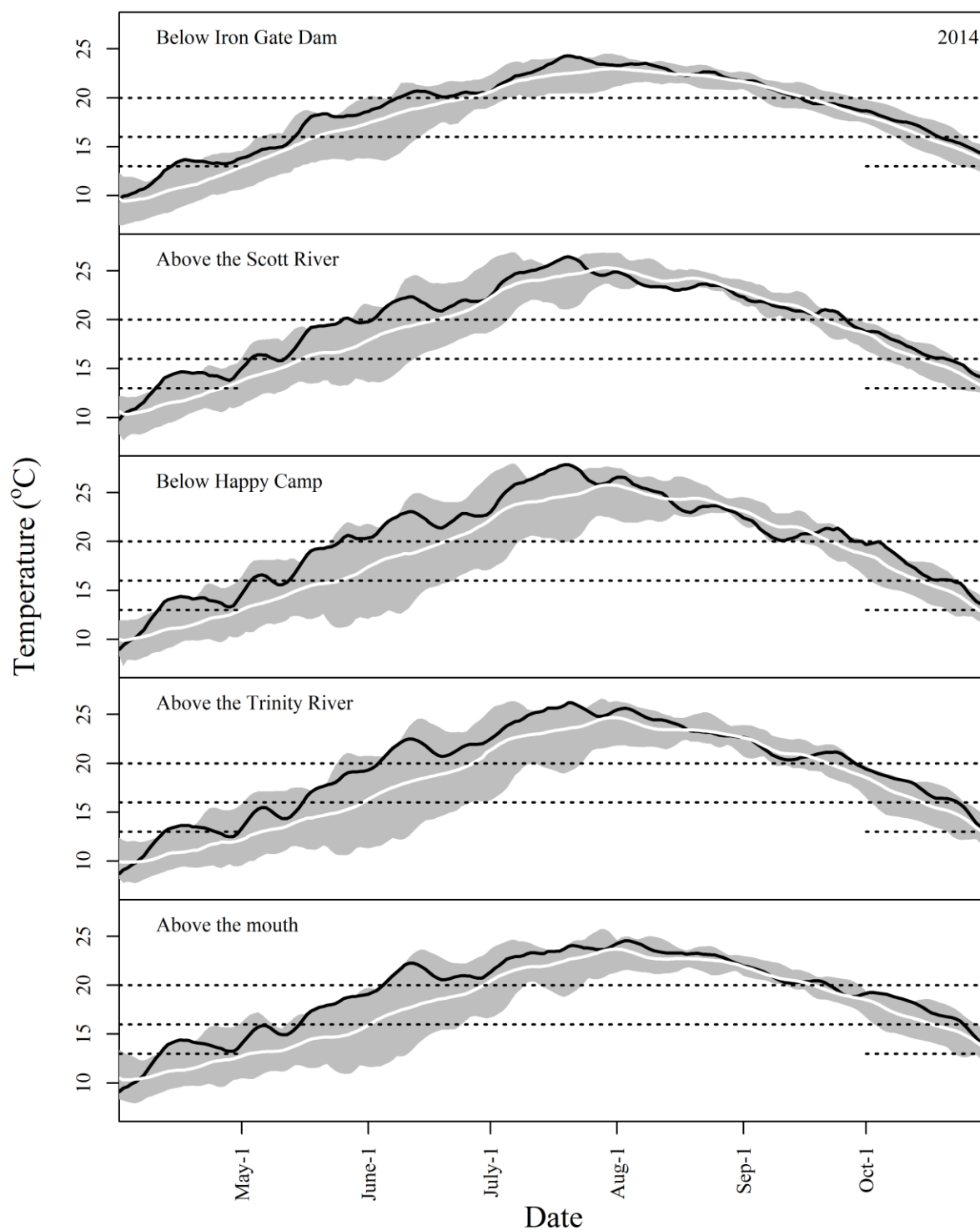
Appendix D12. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2011, with historical conditions. Black line = 7DADM water temperatures in 2011; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



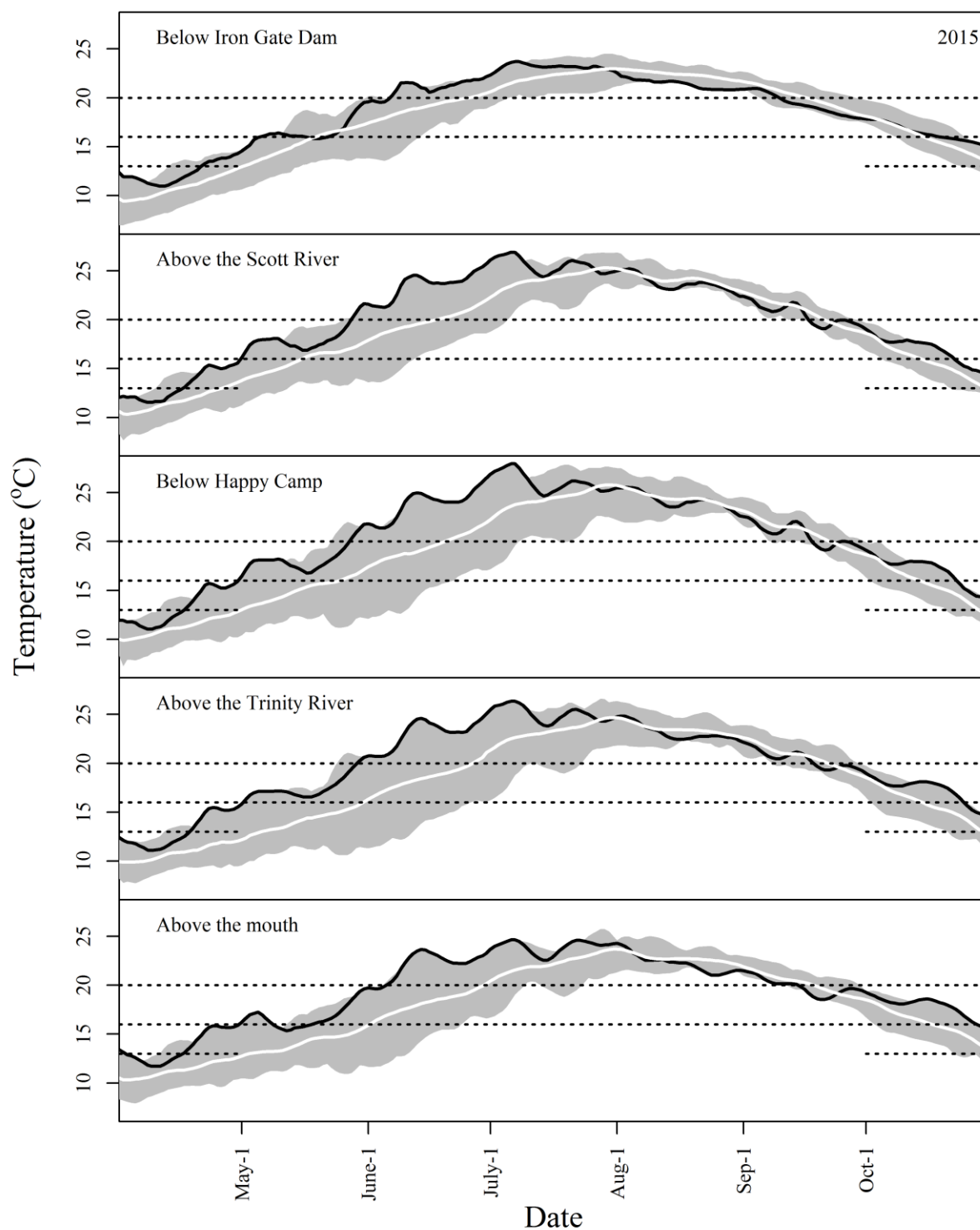
Appendix D13. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2012, with historical conditions. Black line = 7DADM water temperatures in 2012; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



Appendix D14. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2013, with historical conditions. Black line = 7DADM water temperatures in 2013; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



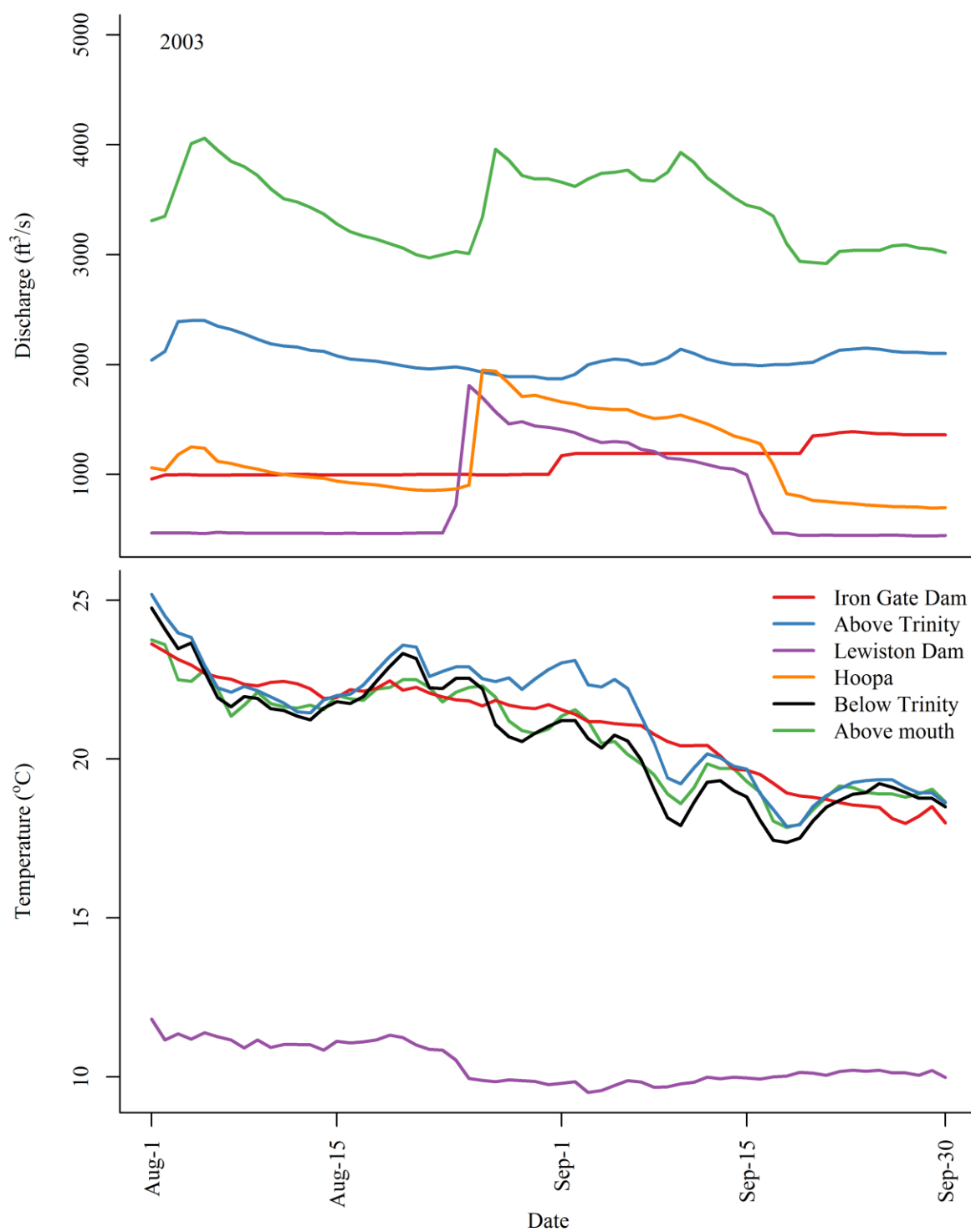
Appendix D15. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2014, with historical conditions. Black line = 7DADM water temperatures in 2014; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



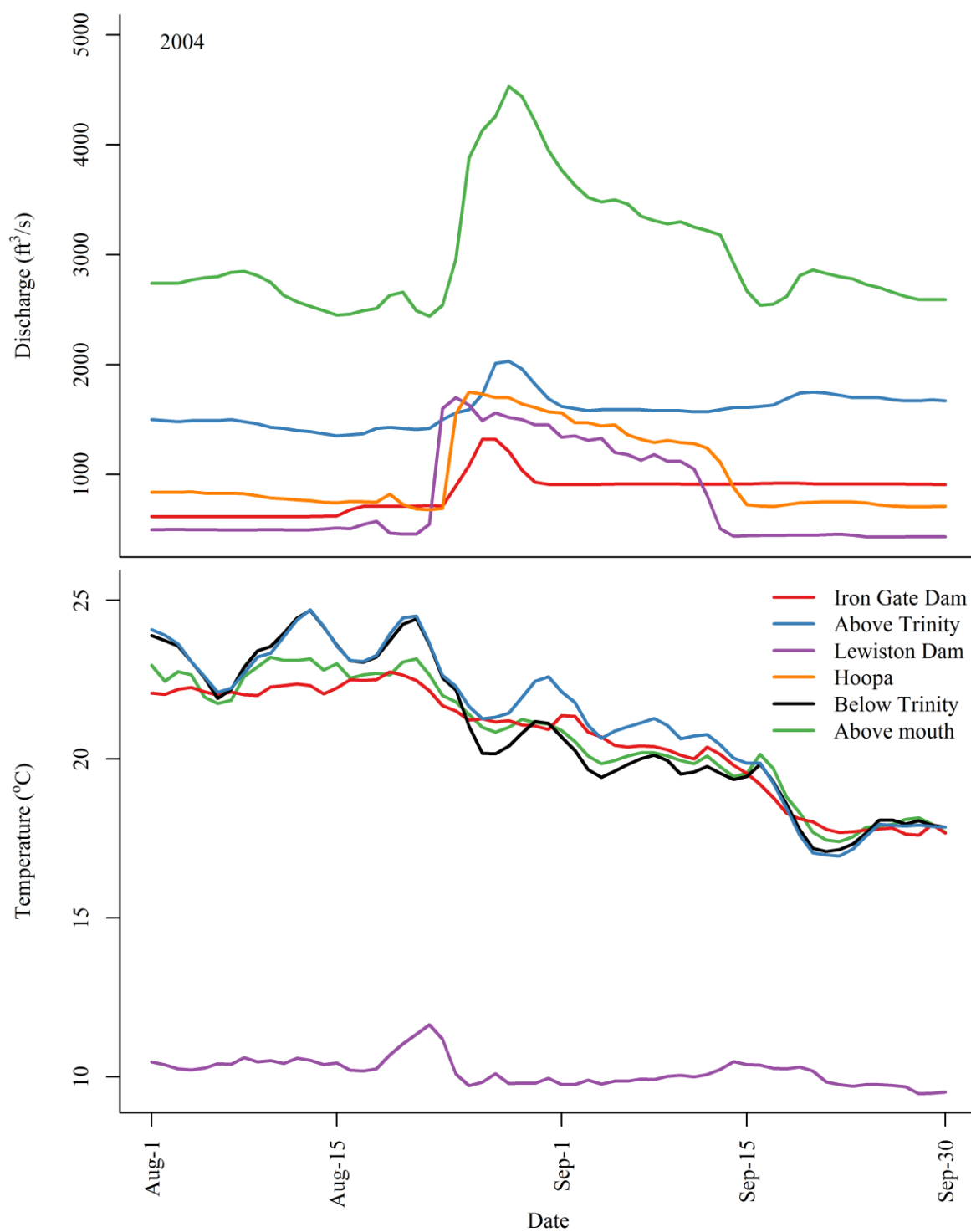
Appendix D16. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2015, with historical conditions. Black line = 7DADM water temperatures in 2015; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



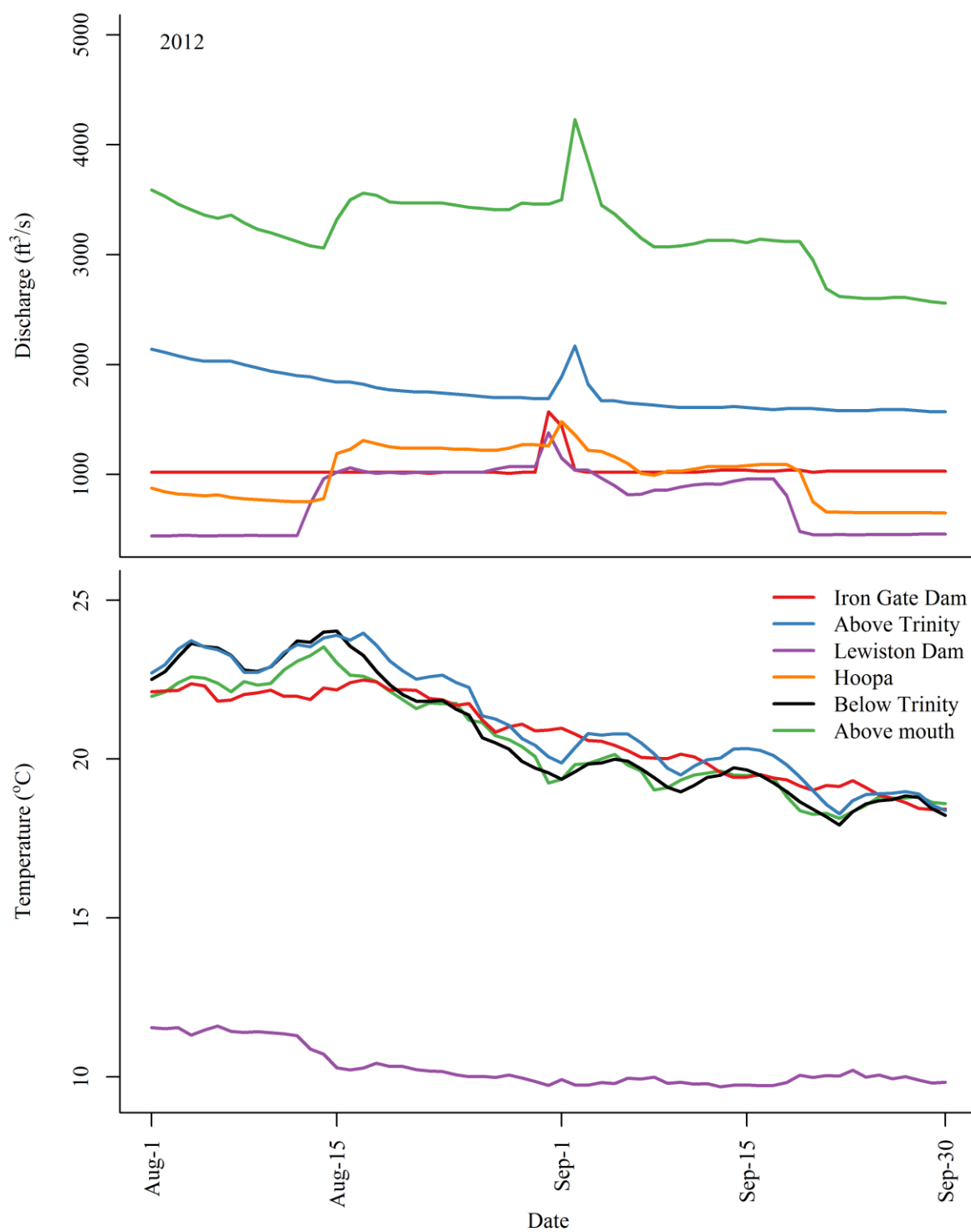
Appendix E. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers during supplemental flow periods from Trinity Reservoir.



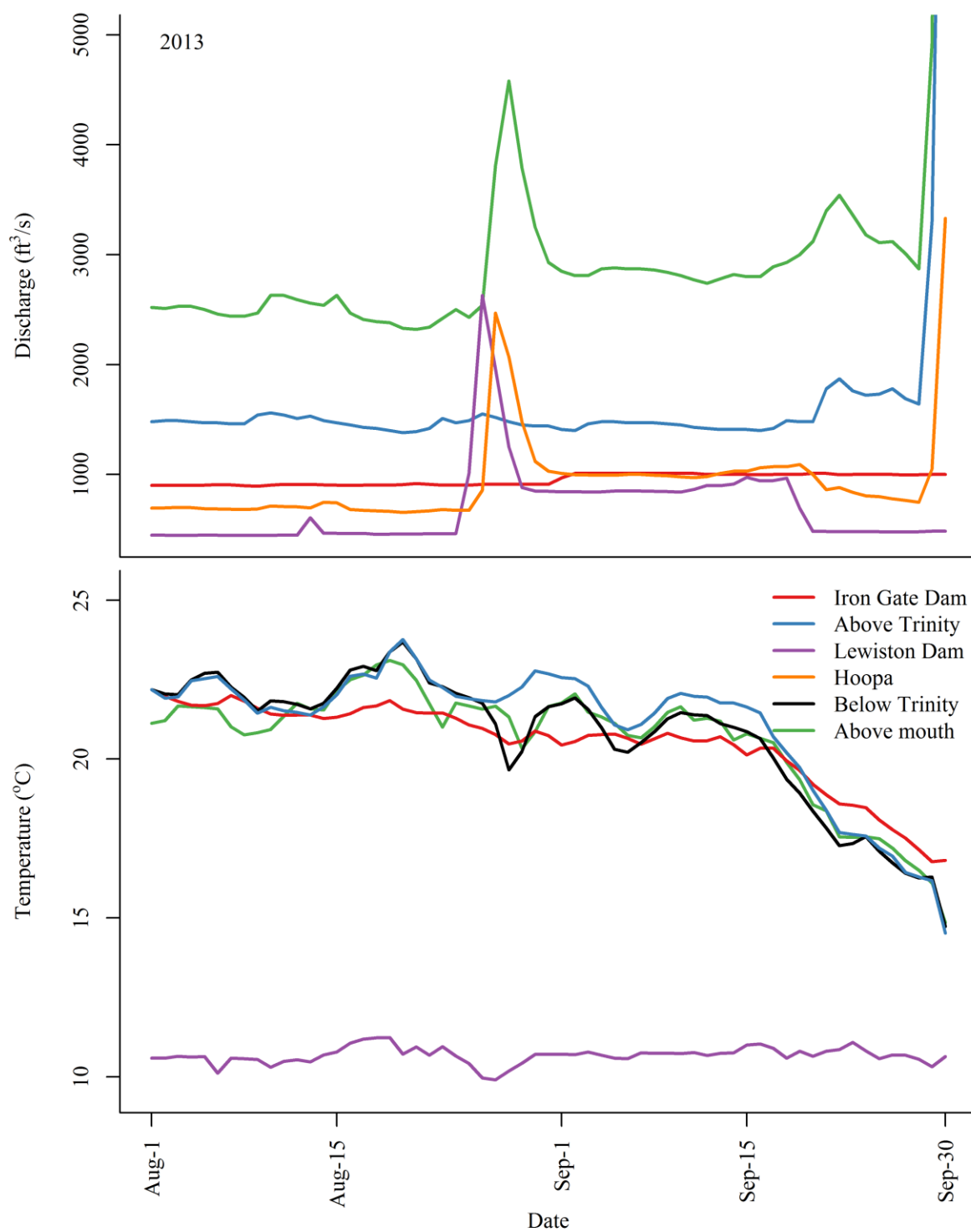
Appendix E1. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2003.



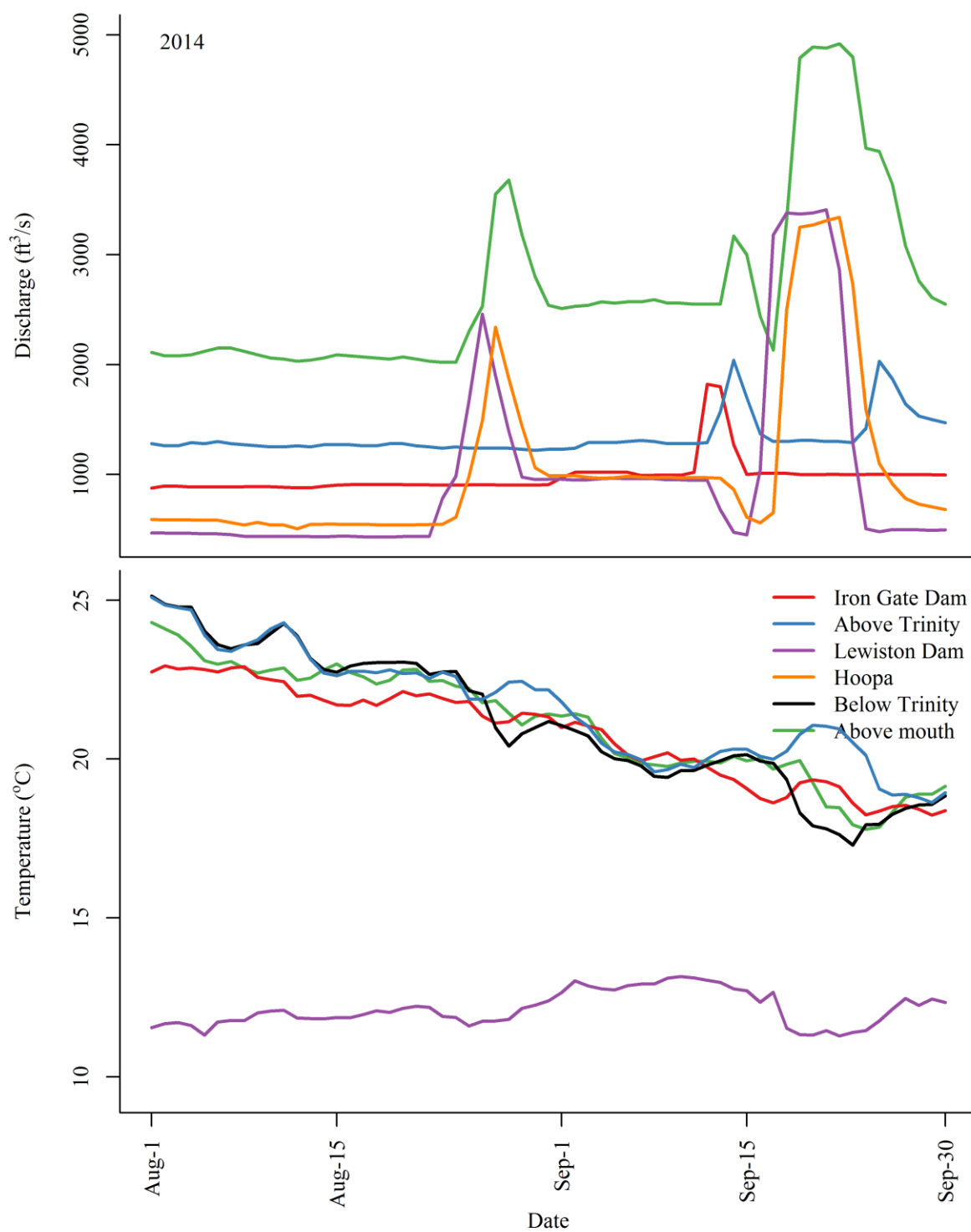
Appendix E2. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2004.



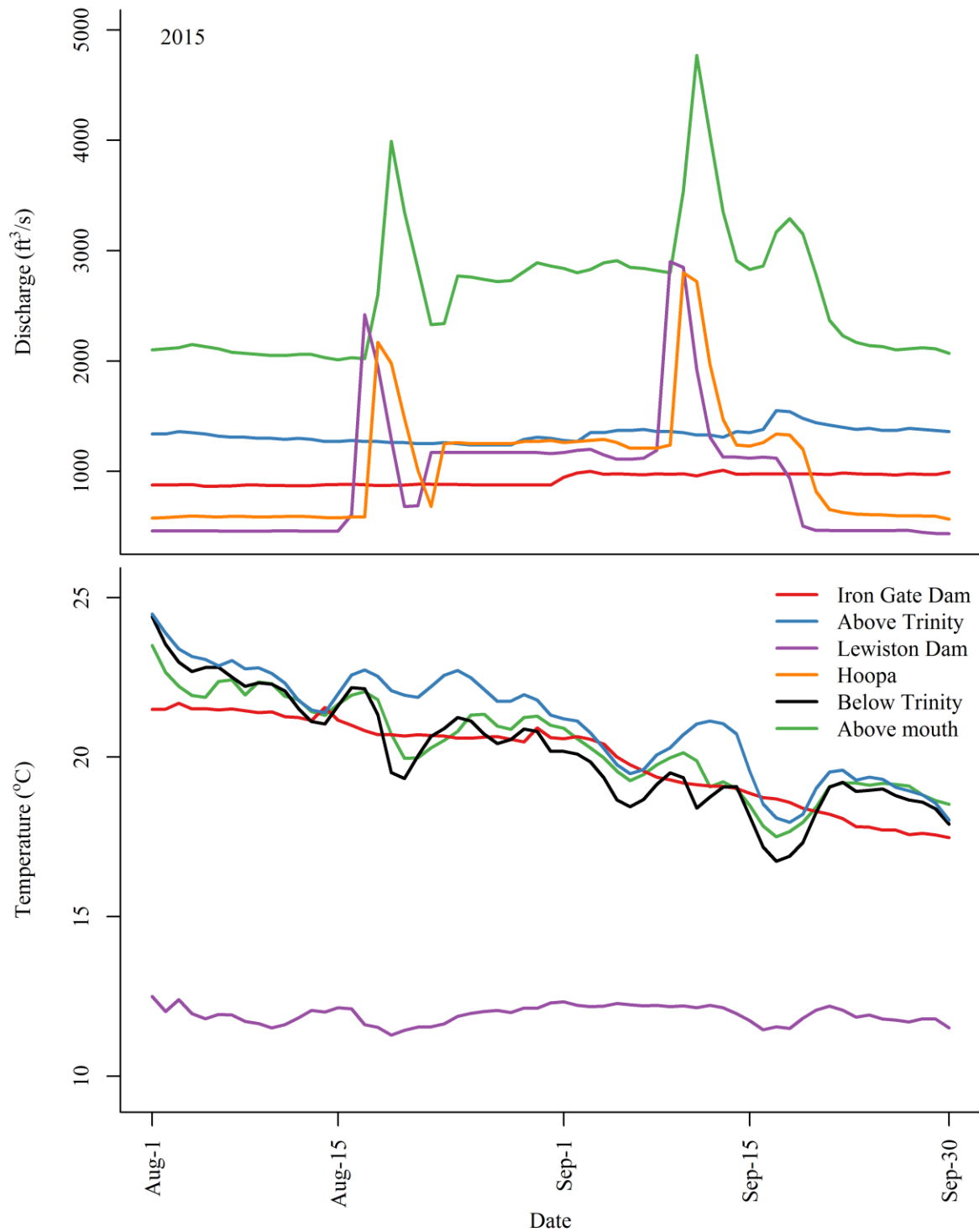
Appendix E3. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2012.



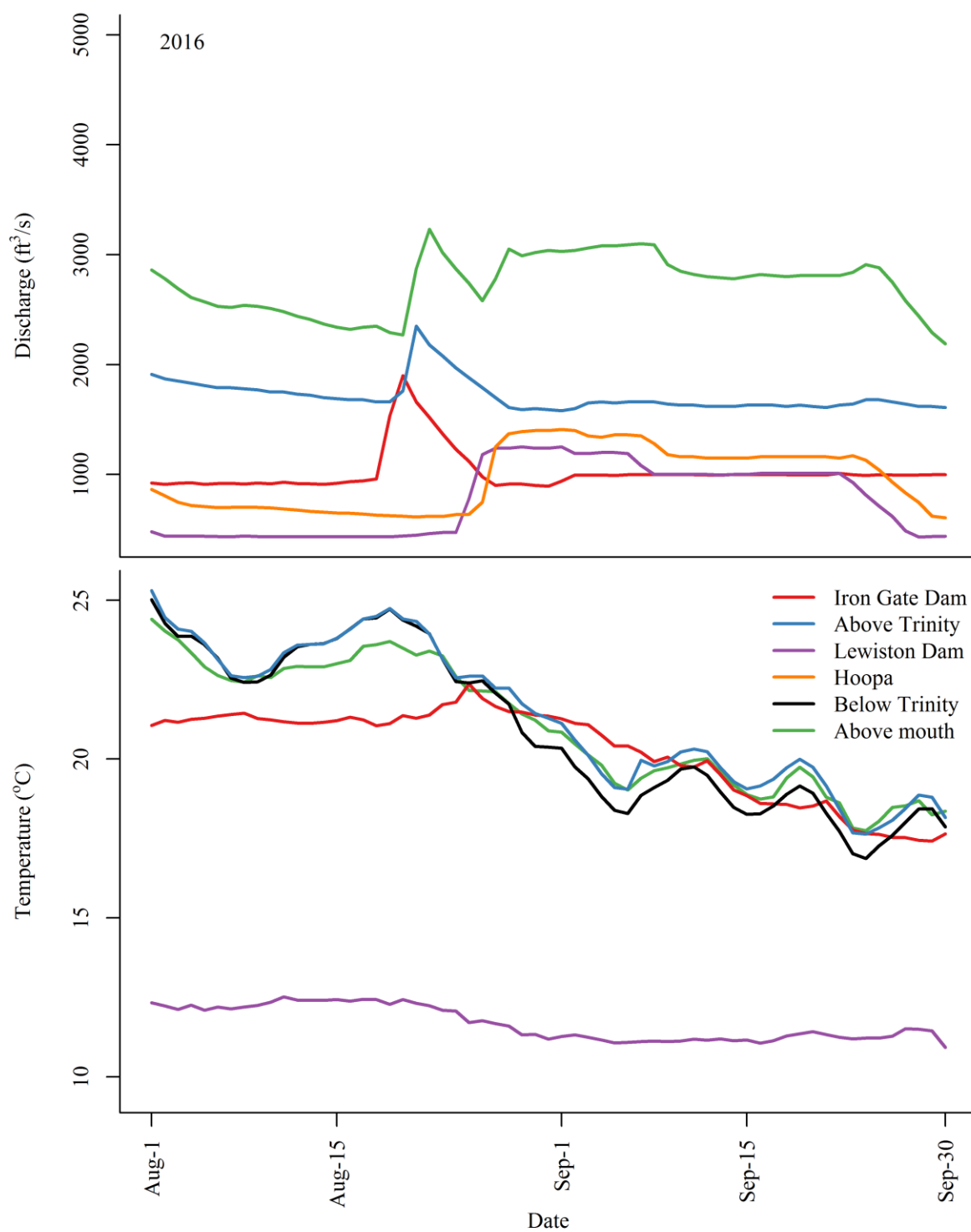
Appendix E4. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2013.



Appendix E5. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2014.



Appendix E6. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2015.



Appendix E7. Mean daily water temperatures and river flows at select locations in the Klamath and Trinity rivers before, during, and after supplemental releases from Trinity Reservoir, August 1 – September 30, 2016.